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Evaluation of alternative Hand-felling Systems for Small Trees

EVALUATION OF ALTERNATIVE

HAND FELLING SYSTEMS FOR SMALL TREES

Prepared for

UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

by

SIRCLE ENGINEERING

SPOKANE, WASHINGTON

FINAL REPORT

on

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COOPERATIVE AGREEMENT

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FORWARD

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The summary of findings and recommendations resulting from this Cooperative Agreement work, performed during the period of December 1982 to August 1983, is the subject of this report.

This report was submitted in September 1983.

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EXECUTIVE SUMMARY

Falling trees smaller than six-inch b.h.d. is usually accomplished by a cutter with a standard long-bar chain-saw, but to cut the stump close and parallel to the ground the cutter must work in a stooped position, or the stump is tall and/or cut on an angle to leave a "staub".

To pile the material the cutter must quickly release the saw and push the falling stem in the general direction of the pile; pile the stem(s) later; have an assistant piling; etc. and in dense steep-terrain stands these task-problems are compounded.

To achieve the ultimate objectives of greater cutter safety; reduced physical effort; increased productivity; more low-cost material recovery; and improved finished-site quality; this task was initiated to evaluate alternative methods of hand-falling small trees. To this end the following findings are reported:

- There appear to be few viable ways to improvise better or different uses for existing chain-saw technology.

- One potential concept incorporates a bow-bar type chain-saw with special handle-modification to use in conjunction with a leverage-frame fitted to the cutters leg, to support and apply force to the saw when falling the tree. The operation can be done with one hand, and the tool immediately released so both hands are free.

- A technically viable system to enhance the falling and recovery task, incorporates a sled-mounted hydraulic-power pack to power a variety of tools, such as; ultra-light weight chain-saw for bucking, lopping and limbing; hand-held clipper-shear on long-reach handle for stems 2½ - 3-inch diameter; hand-maneuvered ground-supported shear requiring no hands to fall trees up to six-inch b.h.d.; in addition to winches to aid in piling and material recovery.

- In the future, walking-machines must be considered the best near term technology to achieve profitable and maximum recovery in dense steep-terrain stands, without destroying the forest.

BACKGROUND

A major forest resource management problem in the Rocky Mountain West is that of achieving effective multiple resource management in economically submarginal stand conditions, especially stands of small timber. Second-growth stands are often overstocked, and must be thinned to meet both timber and nontimber resource management objectives. Broad multiple resource management objectives relating to esthetics, watershed management, wildlife habitat, fire management, insect control, and other such concerns are usually dependent upon carrying out prescribed timber harvesting activities. Major forest landownerships in the Rocky Mountain area have identified this problem as one of their principal management concerns for the 1980's and beyond. Expressed management concerns include:

- need to recover wood fiber from marginal component lands to meet projected softwood production goals;

- need for stand management to combat critical insect, disease, and fuel buildup problems;

- need for stand management to achieve nontimber resource production or enhancement objectives.

An issue frequently at hand is one of economic feasibility; that is, covering the costs of stand treatment with the value of products removed. Even though there are recognized management benifits of treatment, the ability to treat extensive stands is still heavily dependent upon realizing an immediate economic benifit. Research currently underway in the STEM Program addresses the problem of economic feasiblity from two directions: (1) reducing costs of harvesting small stems, and (2) improving product opportunities and value. Present field studies and evaluating costs of stand treatment and potential product recovery and value in small, overstocked lodgepole pine stands. Related studies are evaluating new systems and techniques for improving efficiency in harvesting and handling small stems.

Manual felling is commonly employed in thinning stands of small (2"-6" dbh) timber. Constraints imposed by close spacing, irregular distribution of desireable leave trees, and the need to avoid damage to leave trees, makes it impossible to use feller-bunchers or similiar equipment. Experiments with mechanical thinning have not been encouraging. The manual felling task is one in which there appears to be significant opportunity for improvement in efficiency. Thinning contractors typically use conventional power saws with either bow-bar or long standard-bar. Both hands are required to operate the saw, restricting ability to direct the falling stem. Cutting low stumps, especially parallel to the ground, requires constant stooping. Cutting from a standing position results in each stump becoming a sharp "stob", hazardous to people and equipment.

COOPERATIVE AGREEMENT OBJECTIVES

The purpose of this agreement is to examine the felling task and propose alternative equipment and procedures that can improve efficiency. Specific objectives of this research include:

- Developing a set of "felling system" design criteria, based on present and probable future thinning and material recovery activities in small-stem stands;

- Developing alternative concepts for most efficiently accomplishing the felling task, using "systems" that involve one person and hand-operated equipment;

- Reviewing the current state-of-technology in power units, cutting heads, etc., applicable to the problem;

- Prepare a report of current felling technology, potential new concepts, relative advantages/disadvantages of alternate concepts, prioritization relative to probability of success and acceptance by the industry, and outlook for significant technological improvements.

DESIGN CRITERIA

Describing the circumstances in which a hand-held felling-tool or device may be used is difficult, but the following are some factors considered in conceptualizition, design and evaluation:

- ☐ TREE - SIZE/DESCRIPTION
- ☐ STAND CONDITIONS
- ☐ TERRAIN
- ☐ HARVESTING PERSCRIPTION
- ☐ PRODUCTION
- ☐ ERGONOMICS
- ☐ HUMAN FACTORS

Tree - size/description

The system or device should be adaptable to working forests with tree densities up to 10,000 stems per acre [average spacing 2 feet apart] where very small stems may be in clusters six to eight-inches apart.

Six-inch, breast-heigth-diameter (BHD) would be the largest stem expected to be fallen with this system or device.

Stand conditions

The system or device should be capable of brushing, limbing, bucking, etc. to use in stands where the branches could be dense and close to the ground; and/or where blow-downs and dead-falls exist; and/or where brush density impedes the primary task of falling.

Terrain

The tool or system must be portable over any terrain a man walk, and useable on slopes as steep as 75% (37^{o}) to 100% (45^{o}). And if the work area is less than one-mile from a service area, it is expected, the tool or device would be carried in and out each shift.

Harvesting perscription

The sivicultural treatment may call for; thinning or clear-cutting with partial or complete salvage, or no salvage. However, the system or tool should be adaptable to the most difficult perscription; calling for thinning and complete recovery of felled-material. This implies orderly piling of the downed material for ready removal by skidder, high-line, yarder, etc.

Production

In current thinning operations, when the stems are piled for removal, a three man crew, with one faller using a chain-saw and two men piling, the crew would be expected to process 800 stems per 400 minute day.

The new tool or device would be expected to equal or exceed the rate of: one-stem per ninety seconds per man, which includes movement, piling, servicing, etc.

Ergonomics

The primary task is to conceptualize a device or machine that compliments the ergonomic capabilities of the human body. To this end, some of the following factors are considered:

- ☐ Continuous and intermittent force limitations.
- ☐ Preferred direction of force application.
- ☐ Tool position relative to the body's center of gravity.
- ☐ Maneuverability and working position.

Human factors

Sawyers are expected to be properly equipped with hard-hat, eye and ear protection, gloves, chaps,and hard-toe and slip-resistant foot-wear, but the human-factors effecting tool design considered significant and/or desireable are:

- Safety:
  - Safety from dynamic forces, such as kick-back.
  - Safety from broken cutting tools.
  - Maximum maneuverability to escape from surrounding hazards.
  - Ability to safely set aside the tool.
  - Safety disconnect clutch and/or Dead-man controls.

- Equipment characteristics:
  - Minimum vibration.
  - Muffled noise.
  - Properly directed and/or dispersed exhaust fumes.
  - No hot spots.
  - Low force and comfortably positioned throttle.
  - Adjustable slings, harness, fulcrum point, handles, extension, etc.
  - Low pressure bearing pads.
  - Pads to reduce wear, abrasion and/or resist heat.

- Operational:
  - One free hand while cutting.
  - Both hands free after the cut is complete.
  - Natural operating position (standing).
  - More production;
    - trees down per hour, and/or
    - secondary operations, e.g. piling, limbing, bucking, etc.

CURRENT TECHNOLOGY REVIEW

There are a wide variety of well developed cutting tools for falling small trees and stems up to six-inch diameter, but the devices are universal tools, designed to fill the broadest possible consumer and industrial market needs.

Of course, the broadest line of cutting tools is the chain-saw, which is very finely developed, backed with many good service organizations, and effectively priced. Universal acceptance of the integrally-mounted gasoline-fueled internal-combustion engine-driven chain-saw in the forest industry would be impossible to overcome without a very dramatic technological break through, such as the wire or cable-saw.

The surest way to make this program successful, is to find the best way to enhance the capability of the gasoline-fueled chain-saw.

A variety of electrical-powered chain-saw tools are commercially available, but they are generally NOT high-performance continuous-duty industrial-quality devices, and not much lighter in weight than compareable gasoline-fueled chain-saws. In addition, even the smallest portable engine-driven electrical-generators are heavy and expensive.

Portable hydraulic-power packs are also very massive and expensive, and the standard commerical models are only available with a basic single fixed-displacement pump circuit. But, Hydraulic-power tools and technology offer many good opportunities to develop light-weight high-performance devices and systems to enhance the hand-felling task, plus providing cable-power close-at-hand to aid in recovering the resource.

In the attached tables, the general physical characteristics are summarized for many currently manufactured tools, drives and power-packs, which could be useful in developing, improving and/or enhancing the task of falling small trees. The tables represent a broad cross section of current technologies, and are divided into the following catagories:

- ☐ CHAIN-SAW - gasoline engine powered
- ☐ CHAIN-SAW - electric motor driven
- ☐ CHAIN-SAW - hydraulic motor driven
- ☐ SHEARS - Hydraulic powered
- ☐ POWER-PACKS - electrical
- ☐ POWER-PACKS - hydraulic

Table 1.01. Chain-saw, gasoline-engine powered, physical characteristics.

Manufacturer	Model	Bar length in.	Engine		Weight	Capacity		Notes
			displ. cu.in.	RPM	dry lbs.	Fuel oz.	Oil oz.	
Clinton Clark & Maple Maquoketa IA 319/652-2411	D25 [4hp]	14-17	4.5	5100	21.5	32.0	17.0	Chain speed 2400 fpm
	D35 [6hp]	18-24	5.6	6000	22.3	32.0	17.0	Chain speed 2800 fpm
John Deere	25EV	12-14	1.7	8000	8.4*	6.8	4.7	3000 fpm
	28	10-14	1.83	7500	9.1*	11.8	6.4	2625 fpm
	30	12-14	1.83	7500	9.0*	11.0	7.0	2625 fpm
	40V	14-16	2.15	7500	11.0*	13.0	7.0	2625 fpm
	45EV	16	2.45	8000	10.8*	15.2	7.8	3050 fpm
	50V	16-20	2.7	7500	13.0*	18.0	7.0	3064 fpm
	55V	16-24	3.04	7500	12.1*	16.9	8.5	3064 fpm
	60V	16-24	3.65	7500	18.0*	25.0	12.0	3064 fpm
	70V	16-27	4.31	7500	18.0*	25.0	12.0	3064 fpm
	80EV	16-27	4.8	7500	18.7*	24.3	10.8	3064 fpm
Echo 3150 Mac-Arthur Blvd. Northbrook IL 60062 312/291-2800	CS-280E	12	1.7		7.7	6.8	4.7	
	CS-290EL	12-14	1.7		8.4	6.8	4.7	
	CS 302S	14-16	2.04		9.9	12.0	6.8	
	CS 400EVL	16	2.45		10.6	15.2	7.8	* less bar & chain
	CS 452VL	16-20	2.7		13.2	17.0	8.5	

Table 1.02. Chain-saw, gasoline-engine powered, physical characteristics.

Manufacturer	Model	Bar length in.	Engine displ. cu.in.	Engine RPM	Weight dry lbs.	Capacity Fuel oz.	Capacity Oil oz.	Notes
Echo (cont.)	CS500VL/EVL	16-24	3.04		12.8	17.0	8.5	
	CS656EVL	16-27	3.92		13.7	22.0	10.1	
	CS750EVL	20-27	4.8		18.7	24.0	11.0	
	CS900EVL	23-27	5.59		19.8	31.1	15.6	
Husqvarna	133SE/SG	13	2.1	9600	9.7*	8.4	4.6	
	444SE/SG	13-15	2.7	9300	11.2*	8.4	4.2	
	266SE/SG	15-18	4.0	8500	12.9*	12.8	6.8	
	480CD	18	4.7	8500	15.6*	13.6	8.4	
	285CD	20	5.2	8500	18.0*	13.6	9.3	
	2100CD	24	6.0	8500	18.5*	16.0	11.0	
	44 Rancher	16	2.7	8800	10.1*	8.4	4.0	
	61 Rancher	16	3.8	8300	12.3*	12.8	6.8	
	65	18	4.0	8000	14.5*	12.8	6.8	
	50 Rancher	15-18	3.0	8400	11.4*	10.2	4.8	
	35VR/VRA	12-14	2.1	7800	7.9*	5.6	2.4	
Lombard P.O. Box 86 Harrison, OH 45030 812/637-3213	AP22D-1	12-14	2.2		7.8*	12.0	7.0	* less bar & chain
	AP24D	14-16	2.4		7.8*	12.0	7.0	
	AP42-SE/D	16-28	4.2		14.8*	28.0	6.0	
	AP42DAV	16-28	4.2		16.0*	28.0	6.0	

Table 1.03. Chain-saw, gasoline-engine powered, physical characteristics.

Manufacturer	Model	Bar length in.	Engine		Weight	Capacity		Notes
			displ. cu.in.	RPM	dry lbs.	Fuel oz.	Oil oz.	
Homelite	XL	10-12	1.6		8.2	8.5	6.1	Light-duty
P.O.Box 7047 Charlotte, NC 28217 704/588-3200	XL-2	12	1.6		8.9	8.5	6.1	
	Super 2	14-16	1.9		8.2	8.5	6.1	
	VI super 2	16	1.9		10.7	10.0	7.3	
	240	14-18	2.4		9.7	14.7	7.2	Heavy-duty
	150 AO	16	2.6		11.2	16.0	8.0	
	SEZ-AO	16	2.5		11.1	14.3	4.2	
	XL-12	16-24	3.3		13.2*	20.1	2.8	
	SXL-AO	16-24	3.5		14.0*	24.2	5.0	
	330	16-24	3.5		12.5*	16.0	8.0	
	360-AO	16-28	3.5		13.2*	23.3	10.1	
	410	16-31	4.1		15.5*	24.0	12.0	Extra Heavy-duty
	550	16-36	5.1		17.8*	31.0	17.0	
	750	20-43	6.8		23.1*	42.0	18.0	
	C-72	16-36	4.9		19.0*	40.0	8.0	
	SXL-925	16-36	5.0		16.7*	34.0	12.2	
	Super 1050	23-60	6.1		21.2*	49.3	7.7	
	SWIZ66	19-37	4.7		22.1*	53.0	7.0	
	S1130G	16-60	6.1		26.0*	46.8	10.0	* less bar & chain.

Table 1.04. Chain-saw, gasoline-engine powered, physical characteristics.

Manufacturer	Model	Bar length in.	Engine		Weight dry lbs.	Capacity		Notes
			displ. cu.in.	RPM		Fuel oz.	Oil oz.	
Pioneer	P12/P12S	12-14	2.1		7.5*	10.5	4.2	chain speed
775 Neal Dr. Peterborough Ontario, Canada K9J6X7 705/748-5333	1074	14-16	3.1		11.0*	16.0	5.1	
	P26	16	3.1		11.0*	16.0	5.1	
	P28/P28S	16	3.1		12.8*	16.0	5.1	
	Farmsaw	18	4.0	7500	14.8*	27.1	13.0	3281 fpm
	P41/P41S	16-28	4.0	8500	15.6*	27.1	13.0	3719 fpm
	P51/P51S	16-32	5.0	8000	17.7*	33.1	14.3	3500 fpm
	P61/P61S	20-36	6.0	8000	17.9	33.1	14.3	3770 fpm
Poulan	3700	16-30	3.7	8500	13.6*	19.0	12.0	chain speed 13 &14" bow/ 3700 fpm
5020 Flournoy -Lucas Rd. Shreveport LA 71129 318/687-0100	4400	16-36	4.2	7500	16.7*	36.0	13.0	13 &14" bow/ 3280 fpm
	4900	16-36	4.7	7500	16.7*	36.0	13.0	13 &14" bow/ 3280 fpm
	5400	16-36	5.2	7500	16.6*	36.0	13.0	13 &14" bow/ 3280 fpm
	Micro 25	10-16	2.0		7.5*			no bow
	Super 25	16	2.3		9.4*			no bow
	CV 3400	16-20	3.4		13.5*			13 &14" bow

* less bar & chain

Table 1.05. Chain-saw, gasoline-engine powered, physical characteristics.

Manufacturer	Model	Bar length	Engine		Weight dry lbs.	Capacity		Notes
			displ. cu.in.	RPM		Fuel oz.	Oil oz.	
McCulloch 5400 Alla Rd Los Angeles CA 90009 800/423-6302	PM-155	12	2.0		10.9*	10.8	3.2	
	PM-165	14	2.0		10.9*	10.8	3.2	
	PM-355	14	2.1		11.1*	11.0	3.4	
	PM-365	16	2.1		11.1*	11.0	3.4	
	PM-375	16	2.1		11.5*	11.0	3.4	
	PM-515	16	2.3		11.3*	10.8	3.2	
	PM-10-10S	16-28	3.5		15.6*	24.0	9.6	
	PM-655	16-28	3.7		15.6*	16.6	14.5	
	PM-700	16-28	4.3		15.6*	24.0	9.6	
	PM-805	16-33	5.2		17.5*	25.6	9.6	* less bar & chain.
Sach-Dolmar 708 Florence Atlanta,TX 75551 214/796-7936	105	14-16	2.5		11.0			
	108	14-16	2.5		11.0			
	112	15-24	3.1		14.0			
	114	15-24	3.1		14.7			
	117	15-24	3.7		15.5			
	119	15-24	3.7		15.7			14" bow
	123	17-36	4.2		19.6			15" bow
	133	17-36	5.2		20.0			15" bow
	153	17-36	6.0		22.0			15" bow

Table 1.06. Chain-saw, gasoline-engine powered, physical characteristics.

Manufacturer	Model	Bar length in.	Engine		Weight dry lbs.	Capacity		Notes
			displ. cu.in.	RPM		Fuel oz.	Oil oz.	
Stihl 536 Viking Dr Virgina Beach VA 23452 804/486-8444	009	10-16	2.3		7.9*			
	010/011AV	10-16	2.5		9.1*			
	015L/AV	10-16	2.0		8.1*			
	028 /AVEQ	16-20	2.9		11.7*			
	032AV/AVE	16-24	3.1		12.1*			
	041 /AV	16-24	3.7		15.0*			
	038AV/AVE	16-32	3.7		15.0*			
	048AVE	16-36	4.7		16.8*			
	051AVE/AVEQ	17-47	5.4		18.7*			
	056AVE/AVEQ	16-36	4.9		16.8*			
	076AVE	17-48	6.7		19.6*			
	090	21-60	8.4		27.7*			
Skil 4801 West Peterson Ave. Chicago, IL 60646 312/286-7330	1620/2/4	10-14	2.0		7.5*	11.5	6.5	*less bar & chain
	1634	14	2.0		9.0*	11.5	6.5	
	1634	16	2.3		9.4*	11.0	6.0	
	1641	20	3.4		13.5*	19.0	12.0	

Table 2.01. Chain-saw, electric-motor driven, physical characteristics.

Manufacturer	Model	Length Bar in.	Rating HP	Weight lbs.	Electrical requirements			Notes
					amps	volts	watts	
Black & Decker Box F Hampstead, MD 21074 301/239-5368	3801-10	10		8.9	10.5	120	1400	
	3802-10	14		10.4	11.5	120	1540	
	3803-10	16		10.9	12.5	120	1680	
Homelite P.O. Box 7047 Charlotte, NC 28217 704/588-3200	XEL-10	10		8.6	11.0	120	1470	
	XEL-12	12		9.6	11.0	120	1470	
	XEL-14	14-16		9.9	11.0	120	1470	
McCulloch 5400 Alla Rd. Los Angeles, CA 90009 800/423-6302	Electra-MAC-8	8	.75	5.8	7.0	120	940	Chain speed, fpm 1200
	MAC-10	10	1.5	8.7	9.5	120	1270	2000
	MAC-12	12	1.75	8.8	10.5	120	1400	2000
	MAC-12A	12	1.75	8.8	10.5	120	1400	2000
	MAC-14	14	2.0	10.4	11.5	120	1540	2000

Table 3.01. Chain-saw, hydraulic motor driven, physical characteristics.

Manufacturer	Model	Length Bar in.	Weight lbs.	Hydraulic requirements		Notes
				Flow GPM	Pressure psi	
Stanley	CS-04	12-18	8.0	3-5	1000-2000	pistol grip
3810 S.E. Naef Road	CS-07	12-18	8.0	7-9	1000-2000	pistol grip
Milwaukie,	CS-23	12-18	9.0	7-9	1000-2000	pole saw
OR 97222 503/659-5660	CS-26	12	9.0	3-5	1000-2000	pole saw
New-Draulics	OPS	9-12	9.0	3-6	1000-2000	pole saw
2252 So.3600 West Salt Lake City UT 84119 801/972-3100	OHS	9-12	6.5	3-6	1000-2000	pistol grip
Fairmont	H620	18	9.5	8	1000-2000	standard grip
415 N. Main Fairmont, MN 56031 507/235-3361	H622	15	7.0	8	1000-2000	pistol grip
	H631	12	8.5	8	1000-2000	pole saw

Table 4.01. Shear, hydraulic powered, physical characteristics.

Manufacturer	Model	Hydraulic requirement		Weight lbs.	Cutting capacity inches	notes
		volume GPM	pressure psi			
Stanley 3810 S.E. Naef Road Milwaukie, OR 97222 503/659-5660	PR27	3-5	1000-2000	6.0	1.75	3-5 ft. handle w/ control valve
	PR29/PR30	3-9	1000-2000	9.0	2.25	5 ft. handle w/ control valve
	CT10	3-9	1700-2000	14.9	**	** 12 ton crimping capacity, short stk.
New-Draulics 2252 S.3600 West Salt Lake City UT 84119 801/972-3100	LOP-*-*-*	3-6	1000-2000	5.0	2.00	2-6 ft. handle w/ control valve
Fairmont 415 N. Main Fairmont, MN 56031 507/235-3361	H4701B	4-6	1800-2000	9.3	2.00	4-7 ft. handle w/ control valve
	H4710A	4-8	1800-2000	55.5	3.00*	* cable cutting capacity
H.K. Porter 74 Foley St. Somerville, MA 02143 617/776-8200	17012	.25	7000	15.5	3.00*	* cable cutting capacity
	WTC400	.25	7000	22.0	4.00*	* Cable cutting capacity

Table 5.01. Electrical-generator, power-pack with gasoline-engine drive, physical characteristics.

Manufacturer	Model	Electrical output			Size inches	Weight lbs.	Engine			Fuel		Note
		amps	volts	watts			mfgr.	HP	RPM	tank gal.	use GPH	
Homelite P.O.Box 7047 Charlotte, NC 28217 704/588-3200	E1350	11.2	120	1350	15½ x 18 x 19	62	B&S	3.0	3600	.5	.3	genrl. purpose
	E1700	14.2	120	1700	19 x 19 x 17	67	B&S	4.0	3600	.8	.4	
	E2250	18.7	120	2250	20 x 19 x 17	77	B&S	5.0	3600	.8	.5	
	E3000	25.0	120/240	3000	18½ x 19 x 23	104	B&S	7.0	3600	1.0	.5	
	E4000	33.3	120/240	4000	18½ x 19 x 25	118	B&S	8.0	3600	1.0	.9	
	170A15	12.5	120	1500	20½ x 16 x 24	93	B&S	4.0	3600	.8	.4	heavy duty
	172A20	16.7	120	2000	18½ x 16 x 24	101	B&S	5.0	3600	.8	.5	
	174A24	22.9	120/240	2750	26 x 17 x 27	136	B&S	7.0	3600	1.5	.8	
	174A35	41.7	120/240	3500	26 x 18 x 27	148	B&S	8.0	3600	1.5	.9	
	G3600-1A	15.0	120/240	3600	32½ x 32 x 25	266	Kohler	7.5	1800	1.5	.8	extr.hvy.duty
	177D38	15.8	120/240	3800	31 x 26 x 23	237	Lombardini	8.5	3600	1.2	.5	
	G4800-1A	20.0	120/240	4800	33 x 33 x 25	321	Kohler	9.5	1800	1.5	1.0	
Honda	EM1600	11.7	120	1400	21½ x 14 x 19	98	Honda	*		2.7	.4	*197cc displ.
	EM1800	12.5	120	1500	21½ x 14 x 19	101	Honda	*		2.7	.4	*197cc displ.
	EM2200	15.0	120	1800	21½ x 14 x 19	107	Honda	*		2.7	.4	*197cc displ.
	EM3000	23.3	120	2800	21½ x 17 x 24	141	Honda	*		4.4	.6	*272cc displ.
	EM4000	31.7	120	3800	22½ x 17 x 26	179	Honda	*		4.4	.7	*406cc displ.

Table 5.02. Electrical-generator, power-pack with gasoline-engine drive, physical characteristics.

Manufacturer	Model	Electrical output			Size inches	Weight lbs.	Engine			Fuel		Notes
		amps	volts	watts			mfgr.	HP	RPM	tank gal.	use GPH	
Ford Troy, MI 48084 313/643-2000	KOH-175	15.0	120	1750	15½ x 19 x 15	67	B&S	4.0	3600	.8	.4	
	KOH-350	30.0	120	3500	28½ x 17 x 19	132	Kohler	8.0	3600	2.0	.7	
	KOH-500	42.0	120	5000	28½ x 20 x 21	195	Kohler	12.0	3600	2.0	1.1	
Onan 1400-73rd AveNE Minneapolis, MN 55432 612/574-5000	1.7PC	14.6	120	1750	21½ x 14 x 15	67	B&S	4.0		.8		
	2.2PC	18.7	120	2250	21½ x 14 x 15	70	B&S	5.0		.8		
	3.0PL	25.0	120	3000	26½ x 17 x 19	95	B&S	7.0		1.0		
	3.2PF	27.1	120	3250	24½ x 21 x 35	120	B&S	8.0		1.5		
	3.7PF	31.2	120	3750	24½ x 21 x 35	125	B&S	8.0		1.5		
	5.0PK	41.6	120	5000	24½ x 21 x 35	152	B&S	10.0		1.5		
	6.5PM	54.2	120	6500	24½ x 24 x 35	165	B&S	16.0		1.5		
Pincor 5841 West Dickens Ave. Chicago, IL 60639 312/237-4100	RF12	10.4	120	1250	19½ x 15 x 14	67	B&S	3.0		.8	.6	
	RF20	16.7	120	2000	19½ x 15 x 14	74	B&S	5.0		.8	.5	
	RF30	25.0	120	3000	28½ x 18 x 19	110	B&S	8.0		1.0	.8	
	RF37	30.8	120	3700	28½ x 18 x 19	119	B&S	8.0		1.0	.8	
	RF50	50.0	120	5000	31 x 21 x 20	159	B&S	11.0		1.5	1.0	

Table 5.03. Electrical-generator, power-pack with gasoline-engine drive, physical characteristics.

Manufacturer	Model	Electrical output			Size inches	Weight lbs.	Engine			Fuel		Notes
		amps	volts	watts			mfgr.	HP	RPM	tank gal.	use GPH	
Kawasaki	KG1100	7.5	120	900	19 x 12 x 16	66	K'saki	3.4	3600	.8	.2	132cc displ.
	KG1600	10.8	120	1300	23 x 12 x 17	92	K'saki	5.0	3600	1.8	.3	181cc displ.
	KG2900	19.2	120	2300	23 x 13 x 18	119	K'saki	7.0	3600	1.8	.5	258cc displ.
	KG4000	26.7	120	3200	25 x 20 x 25	195	K'saki	8.0	3600	5.0	.7	341cc displ.
McCulloch 5400 Alla Rd. Los Angeles, CA 90009 800/423-6302	RA 150	13.6	120	1500		80	McCul'h	4.0	3600			
	RA 200	18.2	120	2000		88	McCul'h	5.0	3600			
	RA 330	30.0	120	3300		124	McCul'h	8.0	3600			
	RA 330A	30.0	120	3300		139	McCul'h	8.0	3600			
Skil 4801 West Peterson Ave. Chicago, IL 60646 312/286-7330	1060	14.6	120	1750		63		4.0				
	1062	18.8	120	2250		68		5.0				
	1064	25.0	120	3000		90		7.0				
	1066	31.2	120	3750		113		8.0				
	1068	41.0	120	5000		135		10.0				

Table 6.01 Hydraulic-power pack with gasoline-engine drive, physical characteristics.

Manufacturer	Model	Delivery		Size inches	Weight lbs. dry	Power HP	Fuel		Hyd. resv. Gal.	Description
		GPM	psi				tank Gal.	use GPH		
Stanley 3810 S.E. Naef Road Milwaukie, OR 97222 503/659-5660	HP1-D	8	1400	45 x 23 x 28	280	18	2.5	1.3	4.2	4 wheels, non-towable
	HP1	8	2000	48 x 55 x 42	610	18	14.0	1.3	14.0	2 wheels, towable
Fairmont 415 N. Main Fairmont MN 56031 507/235-3361	HG3558	8			330	16	4.5		4.0	2 wheels, non-towable
H.K.Porter 74 Foley St. Somerville, MA 02143 617/776-8200	HG6401D	¼	7000		88	3.5			5.0	Floor mount.
	HG640	1	1800		88	3.5			5.0	Floor mount.

NEW CONCEPT ANALYSIS

Developing new concepts the following factors were considered:

- ☐ CUTTING TECHNOLOGY
- ☐ DYNAMICS
- ☐ POWER SOURCES
- ☐ DRIVE TRANSMISSIONS
- ☐ ERGONOMICS
- ☐ HUMAN FACTORS

Cutting technology

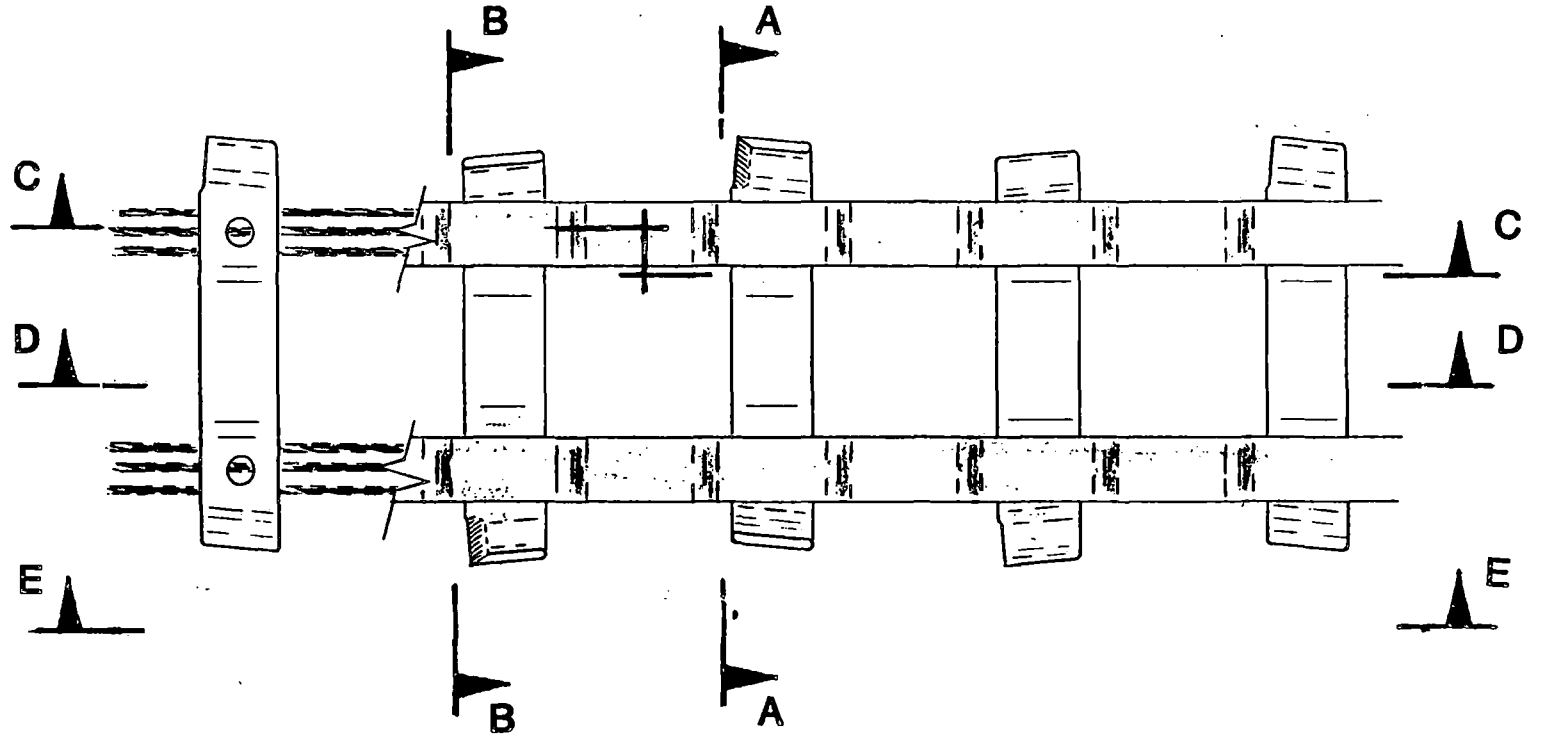
Mechanical cutting is basically a variation of either Sawing or Shearing.

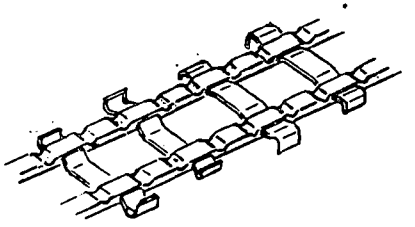
Sawing removes material in small amounts to create a kerf with adequate clearance to allow the tool to move through the material while the saw is performing work. The cutting element designs greatly effect efficiency, but basically the work performed is propertional to the volume of material removed (kerf width).

The torque or force required to move the saw is a function of the chip size, while saw speed determines the amount of material removed in a given time. therefore, the combination of torque and speed determine the power requirements of the saw.

The band-saw is an ideal saw configuration that requires the least amount of power, but drive wheel diameters, tension, tracking and geometry makes the band-saw impractical to use for a hand-held falling device.

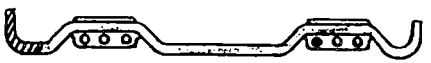
The belt-saw concept, figure 1, 2 and 30, overcome the problem of wheel diameter, tension, and tracking, but the concept is undeveloped, and commercialization would be very costly, therefore an unrealistic concept at the present.



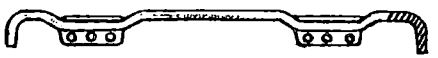


BELT-SAW CONCEPT SKETCHES

Figure 1. Either edge of the belt can cut. When one cutting edge becomes dull the belt is removed, reversed, and reinstalled. The Kerf is expected to be half as thick as a Chain-Saw Kerf.



SECTION A-A



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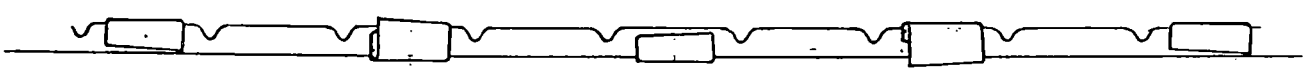
SECTION C-C

SECTION D-D



VIEW E-E

BELT-SAW SECTIONS

Figure 2. The very high tensile-strenght filament cables of graphite, armides, glass, etc. are encapsulated in abrasion resistant elastomers, such as Ureathane, and the inside surface of the belt is knotched for maximum flexibility.

The cable or wire-saw is conceptualized to have cutting teeth around the circular cross section of the cable that could cut in all directions, to overcome the problem of geometry inherent with the band and belt-saws, and would not require lubrication like the chain-saw. But, the concept is undeveloped, and commercialization would be very costly, and therefore can not be considered a concept with near term potential.

The chain-saw cuts a wide kerf, the cutting teeth shapes are not the most efficient, and the chain requires continuous lubrication. But in spite of the several short falls, the chain-saw is well developed, reliable and cost effective. Inaddition the chain-saw tool geometry is well suited for crosscutting service.

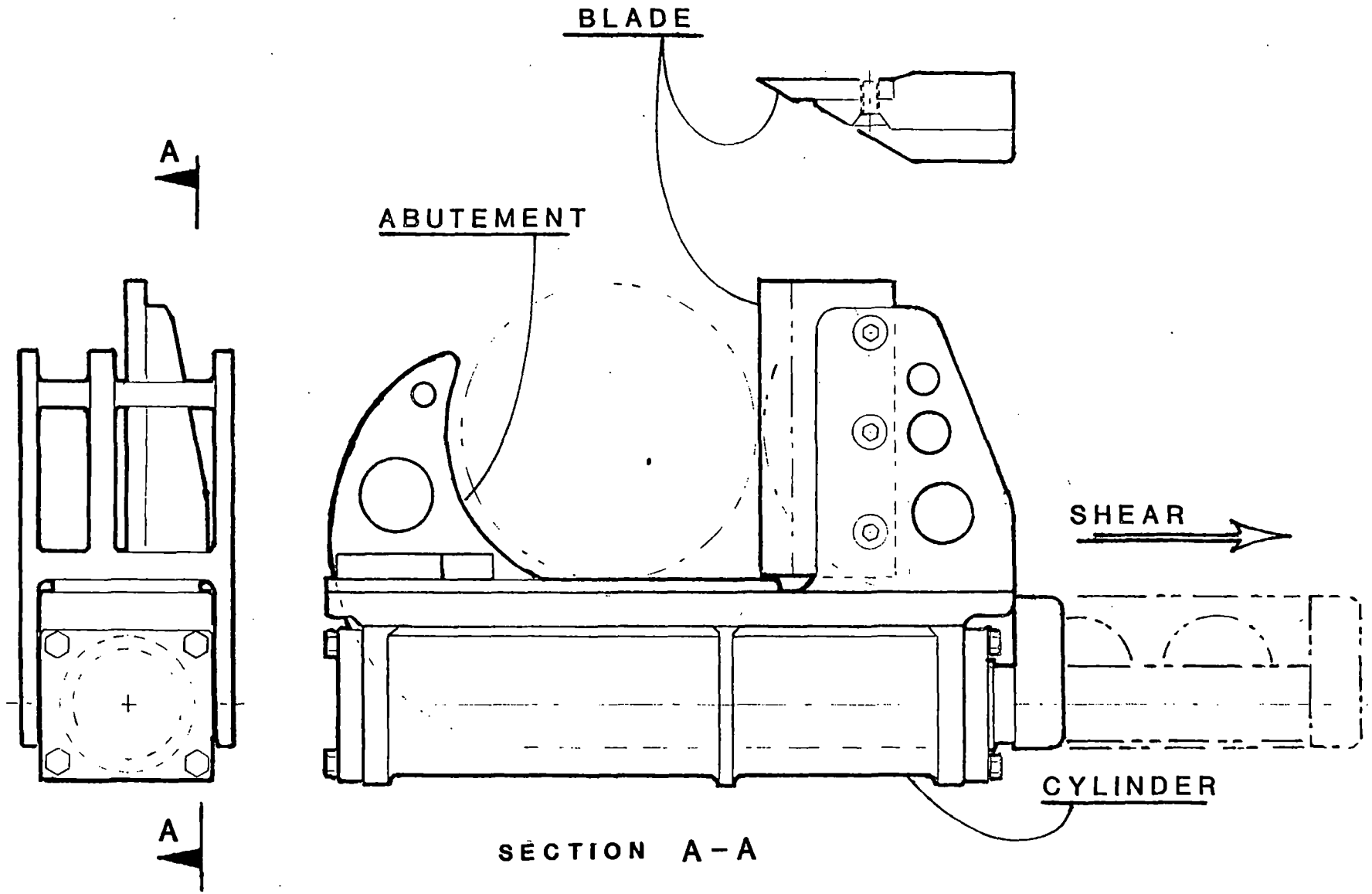
Circular-saws larger than nine inch diameter [3" diameter cutting limit] are impractical as hand-held saw, because of drive torque, kick-back potential, propensity to bind, and gyroscopic forces.

Auger and router cutting tools are highly specialized saws, but the very wide kerf produced demand so much power as to be impractical for hand-held tools.

Shears work by cutting the material and forcing (wedging) the tool through the part. Sharpness and blade shape effect efficiency, but basically the force required is proportional to the thickness and width of the material crossection.

The force maybe developed by a very high-velocity mass, or by direct application of pressure or torque.

The direct application of force in low-speed shears requires a iso-kinetic frame capable of resisting the applied hydraulic or mechanical force, and the frame mass is proportional to the force required. It is estimated that a hydraulic six-inch diameter tree shear, figure , maybe transportable [40 to 60 pounds], but too large and heavy for practical use on small trees.



HYDRAULIC SHEAR WITH CYLINDER

Figure 3. Maximum force is developed in the smallest package by using the full cylinder area, when the cylinder is extended to shear.

Hand-held shears used to prune trees, limited to two-inch diameter stems, weigh about ten-pounds.

A high-velocity shear, equivalent to a hand-axe, would be impractical to duplicate using mechanical or hydraulic devices, due to size and complexity, but a chemical-powered device maybe possible. In depth research on chemical-powered shears is considered beyond the scope of this study, and it is presumed that development cost and practical acceptance, could not justify further study.

In summary the chain-saw is the technically most viable cutting device for hand-held felling tools. Technology is available to develop the belt and cable-saw, but research and development required to commercialize these concepts are substantial, and the demands of only this program and market are tto small to provide adequate economic justification for further development.

Dynamics

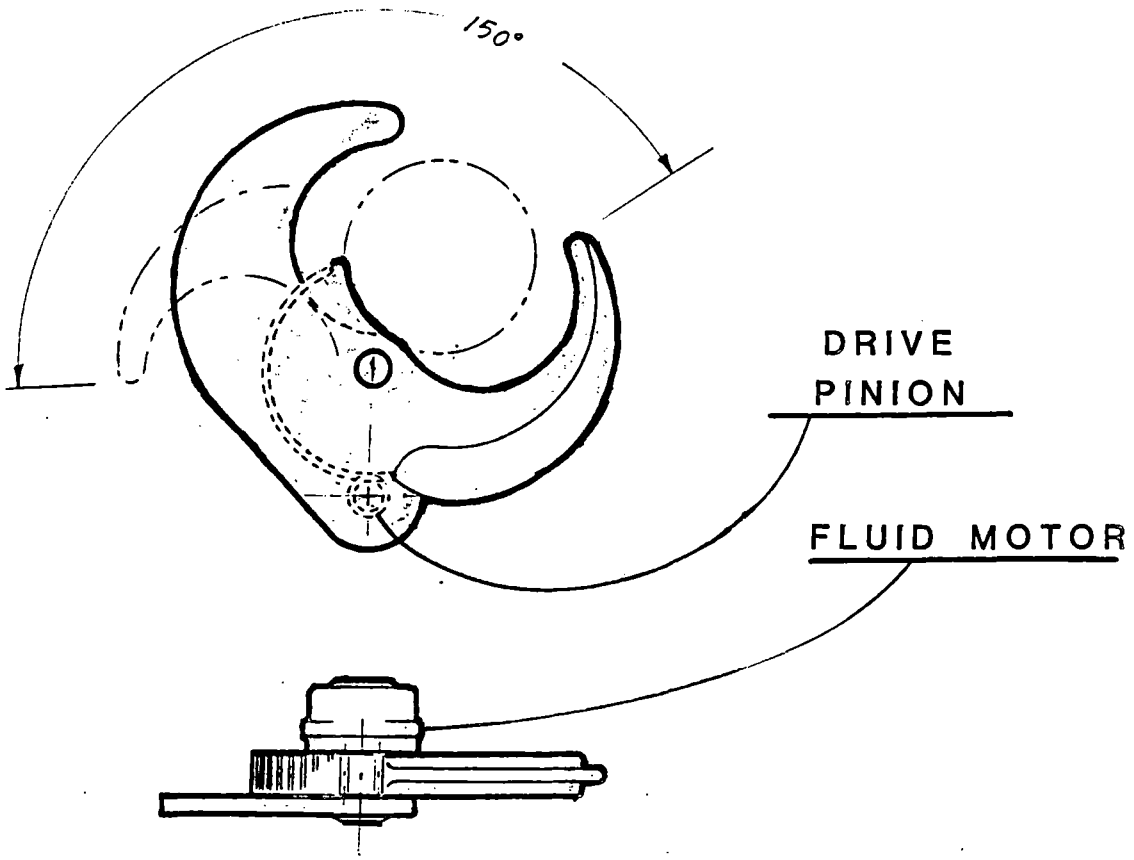
Power is a product of:

FORCE and VELOCITY	:	POWER [linear]
TORQUE and RPM	:	POWER [rotary]

Therefore if linear speed increases the force decreases proportionally; or when the revolutions per minute (RPM) increase the torque decreases; to develop the same amount of power.

Since the mass of a tool proportional to the maximum force or torque, light weight tools must be designed to perform at very high speed.

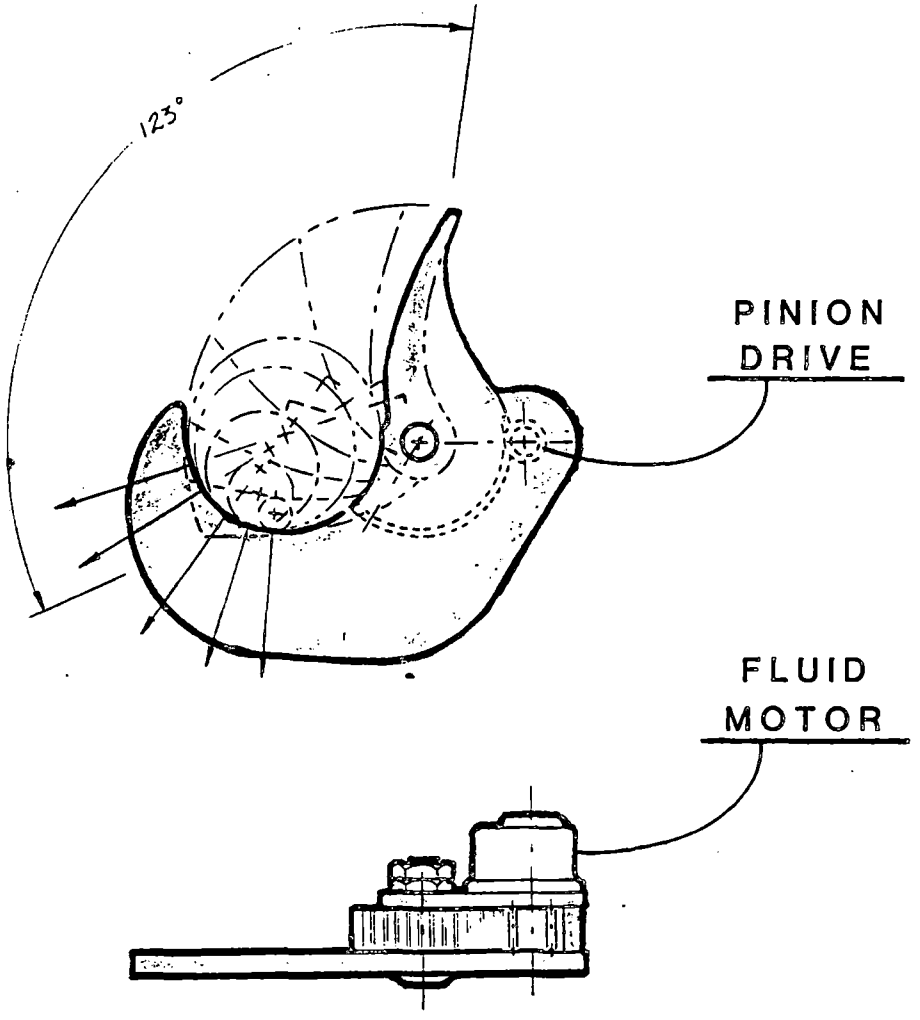
Saws basically run at one speed and perform best at very high speed, which is a reason for the success of the hand-held chain-saw tool.



MECHANICAL / HYDRAULIC SHEAR

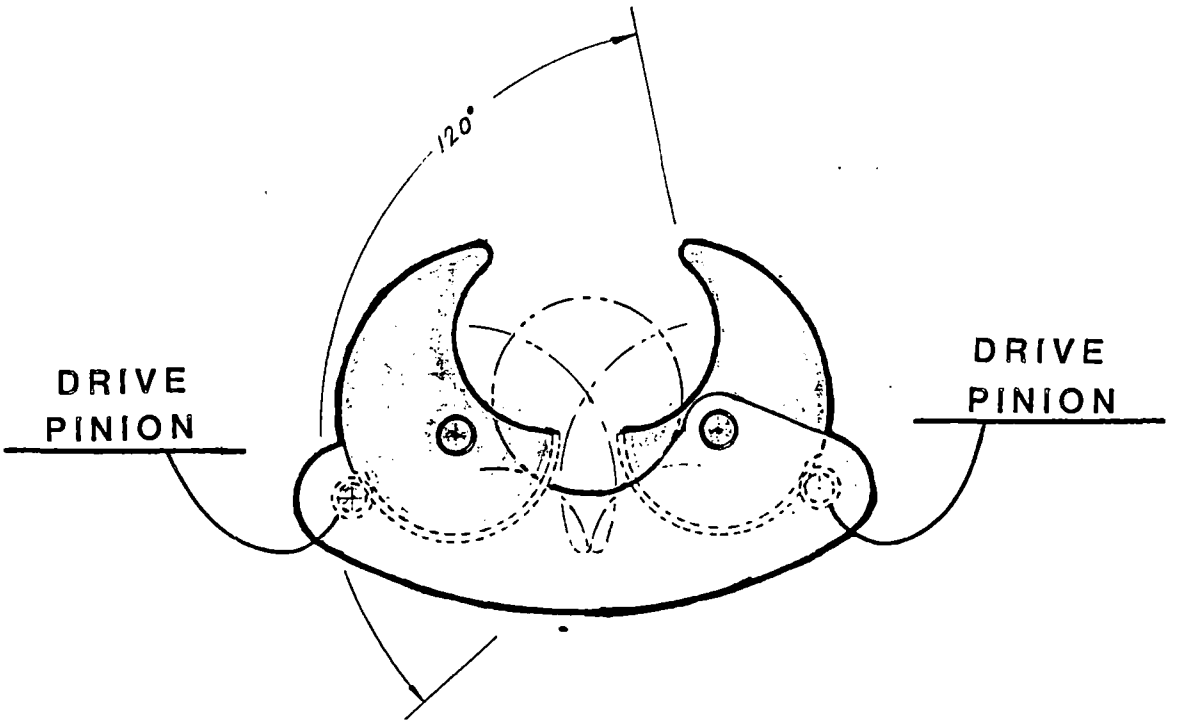
WITH GEAR & PINION DRIVE

Figure 4. Surrounding the stem prevents the tool from "Pushing-Off" when shearing.



MECHANICAL / HYDRAULIC SHEAR
WITH GEAR & PINION DRIVE

Figure 5. The moving abutment is contoured to apply the cutting force normal (perdendicular to the cutting blade.



MECHANICAL / HYDRAULIC SHEAR
WITH GEAR & PINION DRIVE

Figure 6. The double-pinion drive will increase the weight, but not improve performance.

Shears perform best as two-speed devices, opening and closing to the work-piece at high speed, then shifting to a lower speed to develop high-force to perform the shearing work.

Reversible, two-speed, direct-drive, mechanically-driven shears are complex and massive, and are not considered as an option.

Multiple speed hydraulic circuits, figure 7 thru 10 , allow more viable options to increase speed when opening and closing to the work, but the shear-frame mass is determined by the maximum force developed, and while very-high pressure means the cylinder diameter will be small, the cylinder-stroke and shear-frame mass remain the same. The hydraulic-shear head weight is a function of the maximum cutting force, but the high-speed, low-speed circuits substantially reduce the power requirements and size of the hydraulic power unit.

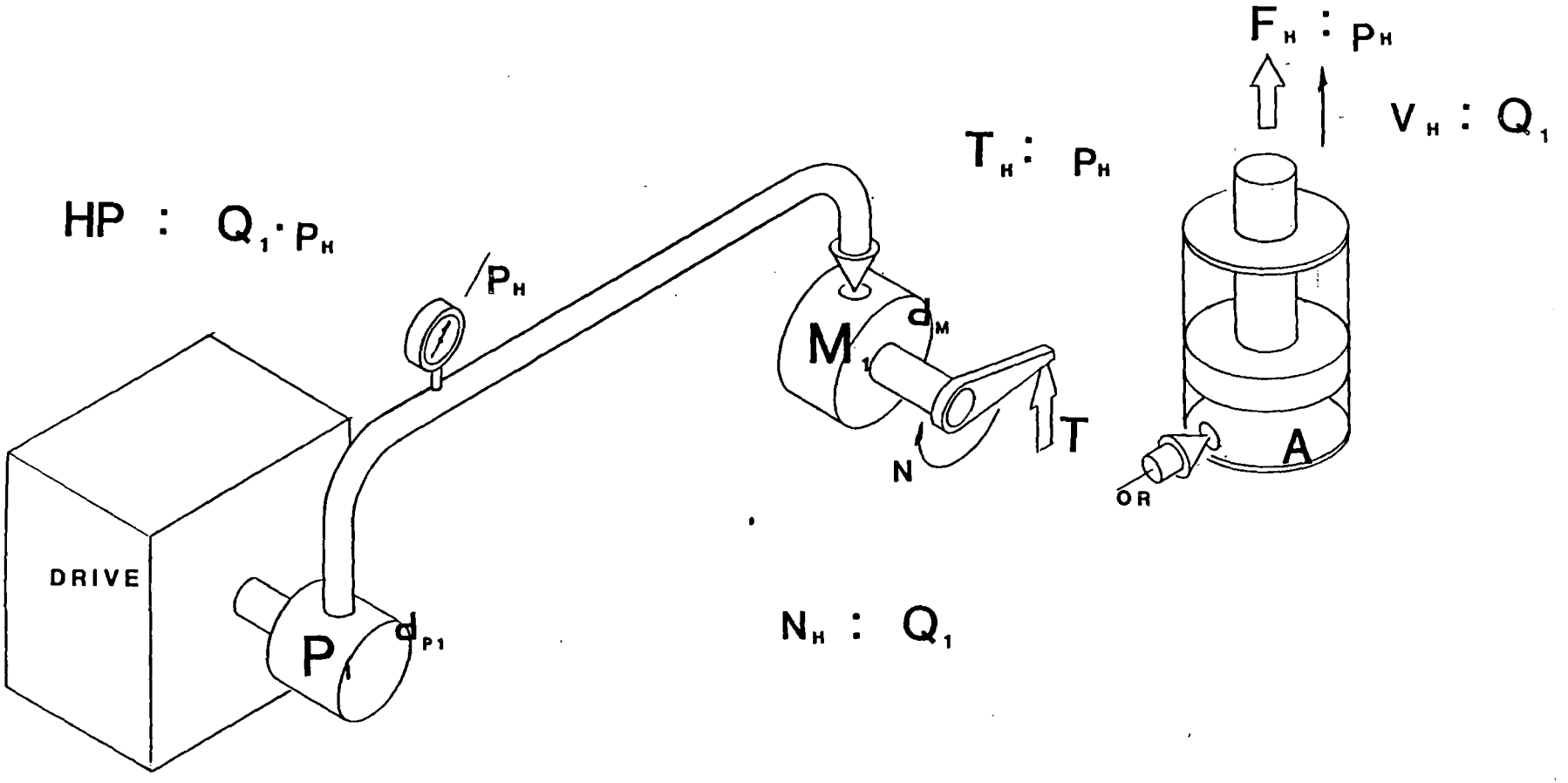
In summary, single-speed high-speed cutting tools [saws] are the lightest tools, and perform the greatest amount of work per unit of weight.

Power source

The only viable portable power source is the gasoline-fueled internal-combustion engine. Whether, used to direct-drive tools, or drive secondary power systems, such as electrical generators or hydraulic pumps.

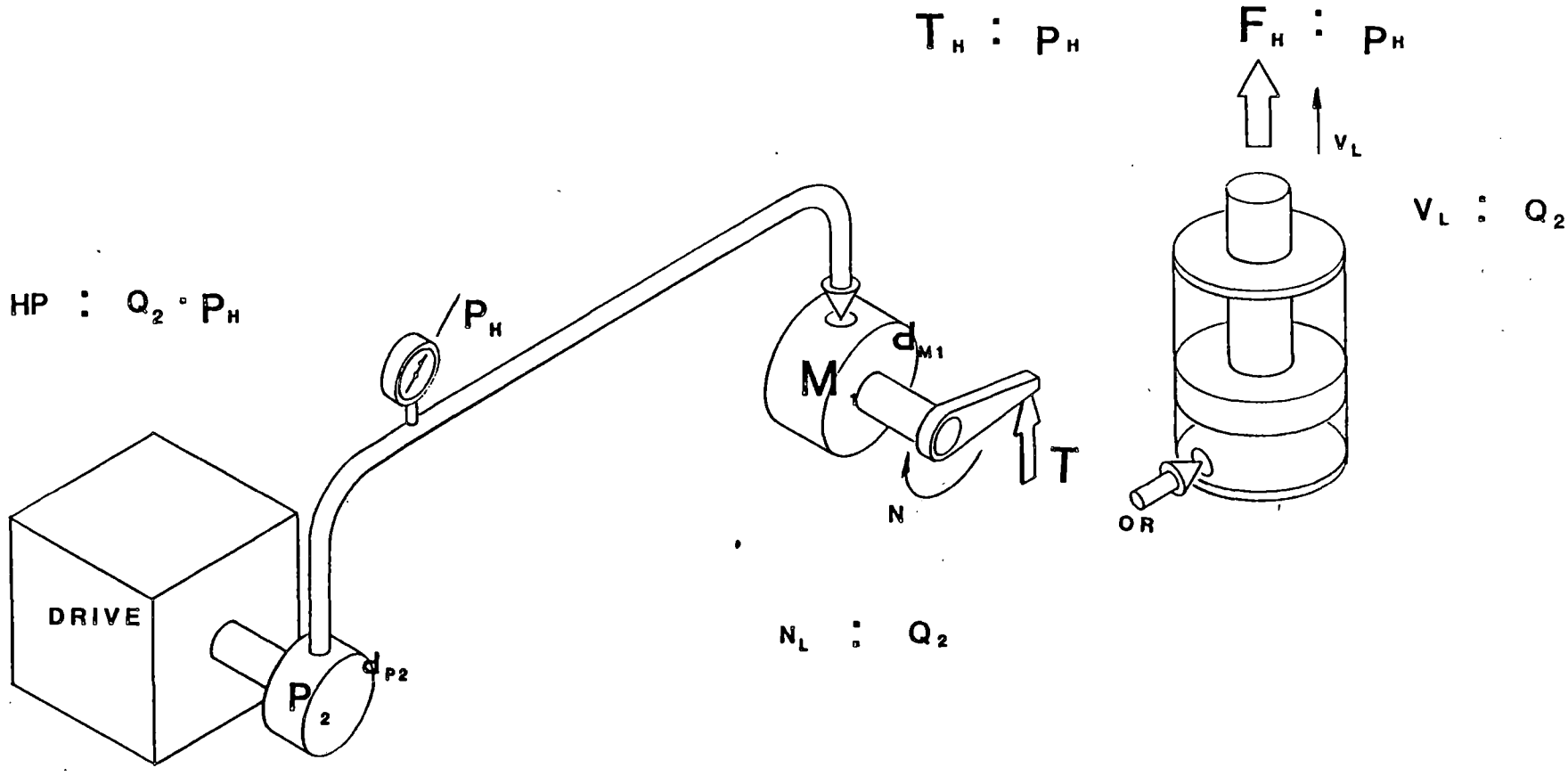
The two basic engine classes considered are; the high-speed intermittent-duty, and medium-speed continuous-duty engines.

The high-speed intermittent-duty engines displace 1.5 to 6.8 cubic inches per revolution (cu.in.) and run at 6000 to 10,000 revolutions per minute (RPM). The engines weigh 4 to 11 pounds, and are ususally direct connected to cutting tools through centrifugal clutches. However, the operating speeds are much too high to drive hydraulic pumps or electrical generators. The power to weight ratio is very high to achieve the low mass weight, but the high-speed engines are generally best suited for intermittent service.



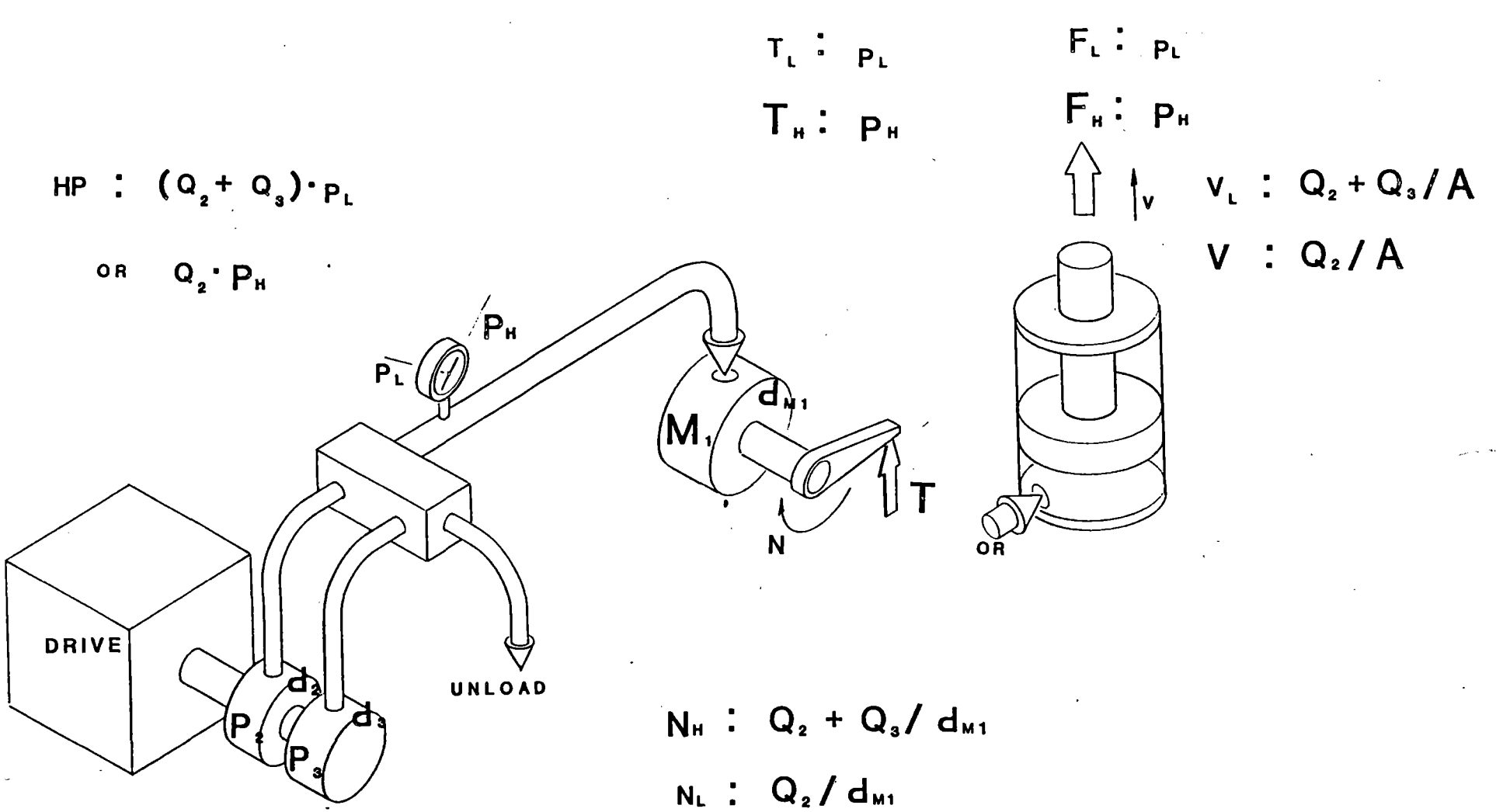
LARGE FIXED-DISPLACEMENT PUMP WITH LARGE DISPLACEMENT MOTOR OR STANDARD CYLINDER

Figure 7. The engine size [HP] (horsepower) is a function of Volume delivered [Q] (gallons/minute -gpm) and maximum pressure [P] (pounds/inch squared - psi), therefore a large displacement pump [d] (inches cube/revelution - cipr) requires a large engine.



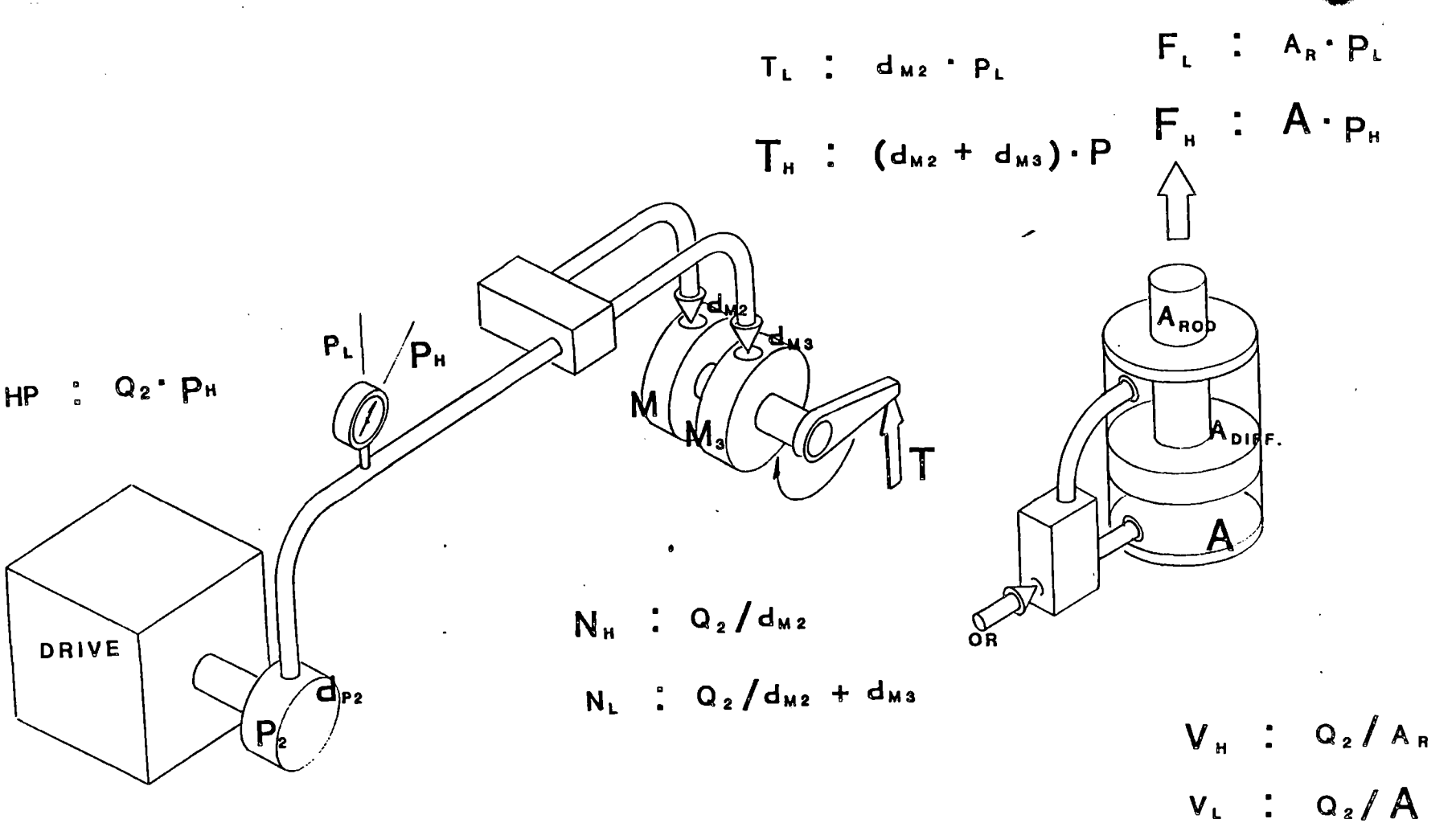
SMALL FIXED-DISPLACEMENT PUMP WITH LARGE DISPLACEMENT MOTOR OR STANDARD CYLINDER

Figure 8. The Torque [T] (inch-pounds - in.lbs.) developed by a motor, or Force [F] (pounds- lbs.) by a cylinder, is a function of Pressure [P] (psi), and maximum pressure [P] is limited by the relief-valve setting, but speed is a function of Volume-Delivered [Q] (gpm). Therefore, a small displacement pump with small engine means the fluid-motor will rotate slowly, or the cylinder will extend slowly.



DUAL SMALL FIXED-DISPLACEMENT PUMP WITH LARGE DISPLACEMENT MOTOR OR STANDARD CYLINDER

Figure 9. When there is no-load two small displacement pumps may deliver oil at low-pressure to spin the fluid-motor, or extend the cylinder at high-velocity. When the torque or load increase the pressure rises and the unloading valve diverts the flow from one pump back to the tank at no pressure, and all engine power is used to develop the high-pressure required for high-torque or high-force, but at reduced speed.



SMALL FIXED-DISPLACEMENT PUMP WITH DUAL-DISPLACEMENT MOTOR OR DIFFERENTIAL CYLINDER

Figure 10. For No-Load, High-Velocity motion, the output of the small displacement pump is directed to only one section of a dual-section Motor, when a load is encountered, the oil is directed to both motor sections to double the Torque [T], but reduce the speed [N]. When oil is directed to both Rod and Base sides of a cylinder, the force and velocity are proportional to the Rod-Area. When a load is encountered, the oil is diverted to only the Base-End and full Force [F] is developed, but Velocity [V] is reduced.

Table 7.01. HYDRAULIC FORCES "F" [lbs] and VELOCITIES "v" [inches/second] RELATIVE TO PISTON AREA, PRESSURE and OIL FLOW.

"D" Dia. [in.]	"A" Area [in.sq.]	"p" Pressure [psi.]		"Q" Oil volume per min. [GPM]				
		2,000	3,000	1	2	3	4	5
1.00	.785	1,580	2,355	4.9	9.8	14.7		
1.50	1.77	3,540	5,310	2.2	4.4	6.5	8.7	10.9
2.00	3.14	6,280	9,420	1.2	2.5	3.7	4.9	6.1
2.25	3.98	7,950	11,930	1.0	1.9	2.9	3.8	4.8
2.5	4.91	9,820	14,730	.8	1.6	2.4	3.1	3.9
3.00	7.07	14,140	21,210	.5	1.0	1.6	2.0	2.7

$$\text{Pump input POWER} = \frac{\text{Oil volume per minute [GPM] x Pressure [psi]}}{1714 \times \text{overall efficiency}}$$

EXAMPLE:

An 85% efficient pump delivering 3 GPM against a 3000 psi resistance requires 6.2 HP.

If the oil is directed into a 2.5-inch diameter cylinder, the piston extends at 2.4 inches per second, and can develop a maximum force of 14,730 lbs.

The medium-speed engines displace 6.7 to 25 cu.in. and run at 1800 to 4000 RPM, and can be governed to run at 3600 RPM for synchronous electrical generation. The engines weigh 22 to 64 pounds and are designed for more continuous operation than the high-speed ultra-light engines, although, quality and reliability vary.

The medium-speed engines are best suited for electrical generator or hydraulic pump drives. The semi-portable electrical generators and hydraulic power units commercially available vary in weigh from 80 to 500 pounds or more, and must be sled or wheel mounted. Ideally, the larger and heavier units should be more reliable than the ultra-light engine-driven tools.

High initial cost for electrical and hydraulic power packs, and the high operating costs (fuel) due to efficiency losses of the intermediate power system, must be considered in evaluating portable power packs and hydraulic and electrical driven hand tools.

Transmission systems

Mechanical transmissions running at high-speed operate at low torque, and generally use the lightest combination of components, however, long-thin high-speed drive-shafts and gears require substantial bearing support to prevent deflection and vibration.

Spring-wound shafts sheathed in flexible covers can perform well at high speed, but they must be carefully applied, and significant bending reduces capacity.

Chains and belts work only in a single plane, and high speed drives must be carefully designed, especially if the two pulleys are far apart.

Rope and cable-drives, figure 11, 16 and 17, have great flexibility, work well at high-speed, and over relatively long spans, but developing adequate traction over the drive pulleys is difficult.

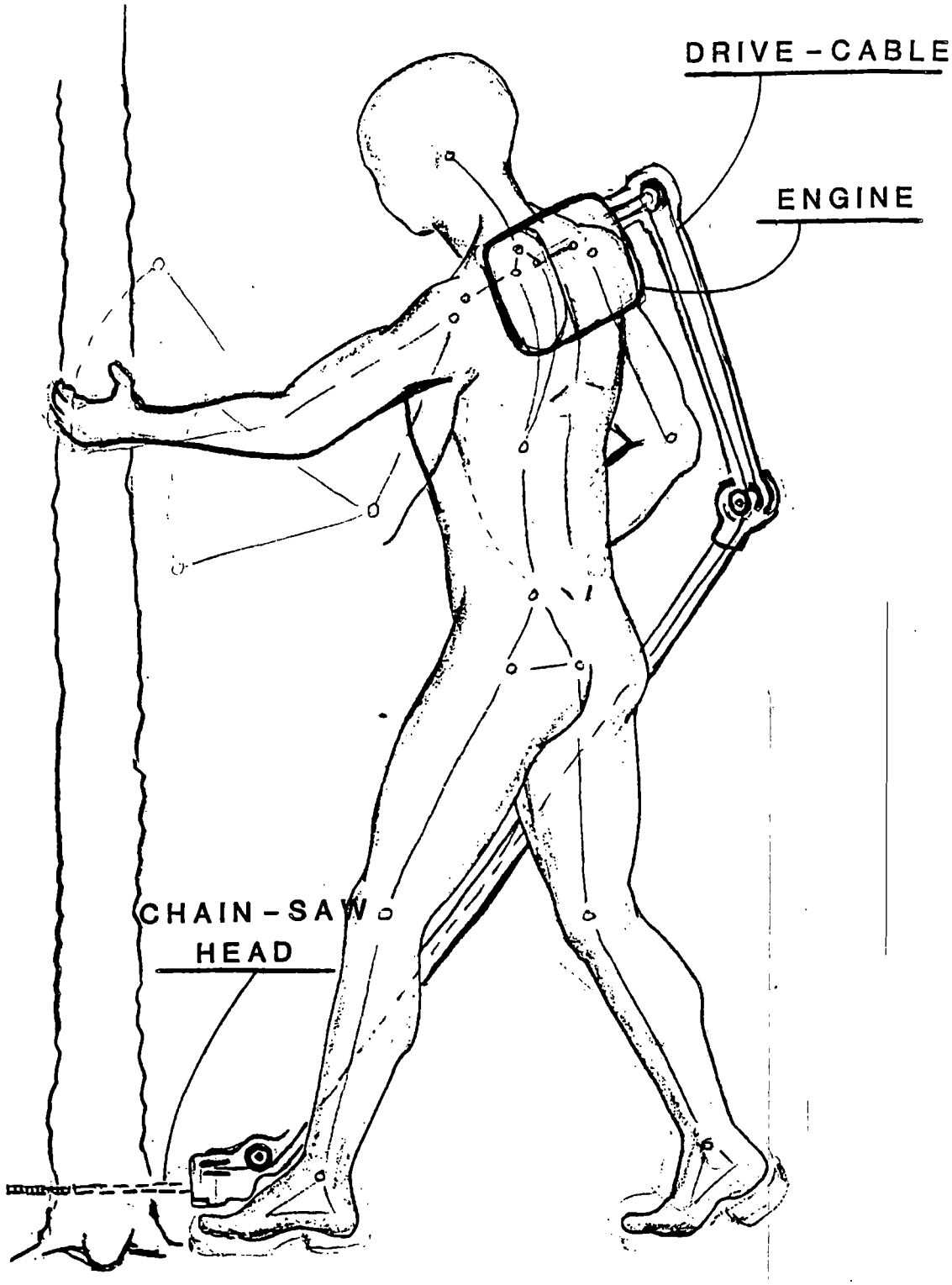


Figure 11. One hand operation can be possible with counterbalanced Arms to reduce the load, which the Sawyer must support.

Electric motors that run at high-frequency (300 Hz) and/or high voltage (greater than 120 volts AC) and/or multiple-phase motors, can develop more power in a small envelope, but the components are not readily available and very expensive.

The 120-volt, single-phase, 60 Hz direct-driven electrical chain-saws on the market are only a few pounds lighter than dry equivalent size direct-driven gas-engine driven chain-saws, but because the electric motors only run 3600 RPM the chain-saws are not as productive. The electric-driven tools have a a small weight advantage, but in addition are relatively quiet, have less vibration and create no noxious fumes near the sawyer.

Hydraulic-motor driven tools are the very lightest weight tools, compared to equivalent electric or engine-driven tools. The hydraulic-drives are noiseless, have little vibration, create no noxious fumes near the sawyer, and can run continuously over 10,000 RPM under load.

The hydraulic hoses are much larger than equivalent electrical power cables, and the hydraulic power units are somewhat larger than portable electrical generators, the hydraulic power can also be more readily used to operate other tools, such as shears and winches.

Ergonomics

The idealized ergonomic design factors for the hand-held falling-tool are summarizied from reference sources[1] and/or postulated, as follows:

- ☐ Total carry-weight, less than 35 pounds.
- ☐ One hand maneuvered-load, less than 6 pounds.
- ☐ Two hand maneuvered-load, less than 15 pounds.
- ☐ Moment load about the hip line, less than 140 in-lbs.
- ☐ Minimum use of back muscles to lift or carry.
- ☐ Minimum torso twist to produce work.
- ☐ Primary action forces;
  - o Push forward.
  - o Push down.

1. Woodson, W.E. Human Factors Design Handbook. New York: McGraw-Hill Book Company, 1981

Human factors

Human-factors are very subjective and an integral function of specific designs. Therefore, while the "Human Factors" general parameters are listed in the DESIGN CRITERIA section, the "Human Factors" comments on specific concepts or devices have been included in the "Personnel Enviroment" portion of the REVIEW AND EVALUATION section.

REVIEW AND EVALUATION

The standard-bar and bow-bar chain-saw tools have been described and "advantage/disadvantage" comments prepared for comparative evaluation with several schemes and devices conceptualized that have validity and potential for further evaluation, design and/or implementation. The devices and schemes include:

- ☐ CHAIN-SAW with STANDARD BAR.
- ☐ CHAIN-SAW with BOW BAR.
- ☐ CHAIN-SAW on EXTENDED TORQUE-TUBE.
- ☐ CHAIN-SAW on LONG-REACH ARM.
- ☐ BELT-SAW in WISHBONE FRAME.
- ☐ WIRE- or CABLE-SAW.
- ☐ CHAIN-SAW with BOW-BAR, modified for STIFF-LEG.
- ☐ SLED-MOUNTED PORTABLE POWER-UNIT and TOOL-CARRIER.

CHAIN SAW with STANDARD BAR:

Description: The hand-held chain-saw with standard bar, 10-36" long, incorporates the well developed direct-driven link-chain fitted with chisel-shaped teeth, and powered by an integrally mounted internal combustion engine. The self-contained tool held with two hands can be used in any attitude. The cutting section is parallel to the saw and bar centerlines. The sawyer places the chain-bar and heel of the saw against the tree trunk and forces the cutting chain into the wood with a semi-rotary motion of the handle, or by twisting the torso when only the chain-bar is against the tree.

Cutter

--- Desireable characteristics ---

* Light Weight.
* Low inertia of moving mass.
* High speed/ low torque.
* Very well developed technology.
* Easy to repair.
* Lowest cost power tool.
* The cutting chain is only moving when the engine RPM is high.
* Good for bucking and delimbing.

--- Undesireable characteristics ---

* The cutting-chain produces a wide kerf.
* Chain-bar lubrication is required.
* Small stems can pinch the bar.
* The longer the bar the more power required.

CHAIN SAW with STANDARD BAR: (cont.)

Drive

--- Desireable Characteristics ---

* Very best POWER to WEIGHT ratio
* Low reaction forces, because of high speed and small mass (inertia).
* Centrifugal clutch engages only at high speed.

--- Undesireable characteristics ---

* The ultra-light weight engines are not sturdy enough for sustained heavy-duty service.
* Small light-weight rotary mass does not have enough inertia to permit overload or lugging.

Ergonomics

--- Best features ---

* The chain-saw is well balance with handles near the center of gravity.
* The unit may be used in any attitude.

--- Least desireable features ---

* The tool must be carried away from the body, producing a high level of arm and back strain.
* To cut trees low and parallel to the ground the sawyer must stoop and/or crouch with the tool away from the body, causing a high level of arm and back strain.
* The torso must twist to apply cutting-feed force to the chain-bar, especially when the heel spikes are not used.
* Two hands are required at all times to maintain control and make a cut.

Personnel environment

--- Good features ---

* The chain-saw can be easily set aside for comfort and safety reasons.

--- Undesireable characteristics ---

* Vibration transmitted from the engine to the hands and arms can be irritating and troublesome
* High engine noise level, close at hand.
* Gasoline fumes near the face.
* Kickbacks are hazardous and not easily controlled.

CHAIN SAW with BOW-BAR :

Description: The hand-held chain-saw with bow-bar is a readily available commercial tool for falling trees and cutting brush. The saw incorporating the well developed link-chain fitted with chisel-shaped teeth is power by an integerally-mounted internal-combustion gasoline-fueled engine. The self-contained tool held with two hands can be used in any attitude. The cutting chain rides in the groove of a teardrop shaped bar, with an open center, and the cuttting edge section is perpendicular to the saw centerline. The sawyer places the nose or front section of the bow bar against the tree trunk and forces the cutting chain into the wood with a pushing force.

Cutter

--- Desireable characteristics ---

* Light weight.
* Low interia of moving mass.
* High speed / low torque.
* Very well developed technology.
* Maintenance is simple.
* Easy to repair.
* Relatively low cost components.
* Bow-bar least susceptible to being pinched.
* Best configuration for cutting brush and small diameter trees.

--- Undesireable characteristics ---

* The cutting chain produces a wide kerf.
* Chain-bar lubrication is required.
* High torque engines required due to heavy Bow-bar drag.

Drive

--- Desireable characteristics ---

* Very best POWER to WEIGHT ratio.
* Low reaction forces, because of high speed and small mass (inertia).
* Centrifugal clutch engages only at high speed.

--- Undesireable characteristics ---

* The ultra-light engines are not sturdy enough for sustained heavy-duty service.
* Small light weight rotary mass does not have enough inertia to permit overload or lugging.

Ergonomics

--- Best features ---

* The chain saw is well balanced with handles near the center of gravity.
* The Unit may be used in any attitude.
* The tool is pushed through the stem.
* The strongest muscles, the legs, can be used to push the tool through the stem.

--- Least desireable features ---

* The tool must be carried away from the body, producing a high level of arm and back strain.
* To cut trees low and parallel to the ground the sawyer must stoop and/or crouch with the tool away from the body, causing a high level of arm and back strain.
* Two hands are required at all times to maintain control and make a cut.

Personnel environment

--- Good features ---

* The chain saw can be easily set aside for comfort and safety reasons.

--- Undesireable characteristics ---

* Vibration transmitted from the engine to the hands and arms can be irritating and troublesome.
* High engine noise level, close at hand.
* Gasoline fumes near the face.
* Kickbacks are hazardous and difficult to control.

CHAIN-SAW on EXTENDED TORQUE TUBE:

Description: The Extended-torque-tube chain-saw concept allows the sawyer to work in an upright position to fall trees. The pivot point of the tool is placed into the ground near the tree trunk and the cutting-chain forced through the tree by pulling the horizontal-lever on the engine housing. The sawyer requires both hands to control the tool.

Cutter

--- Desireable characteristics ---

* Light weight.
* Low interia of moving mass.
* High speed / low torque.
* Very well developed technology.
* Easy to repair.
* Relatively low cost components.
* Satisfactory for bucking and delimbing.
* The cutting-chain moves only when the engine RPM is high.

--- Undesireable characteristics ---

* The cutting chain produces a wide kerf.
* Chain-bar lubrication required.
* Small stems can pinch the bar.

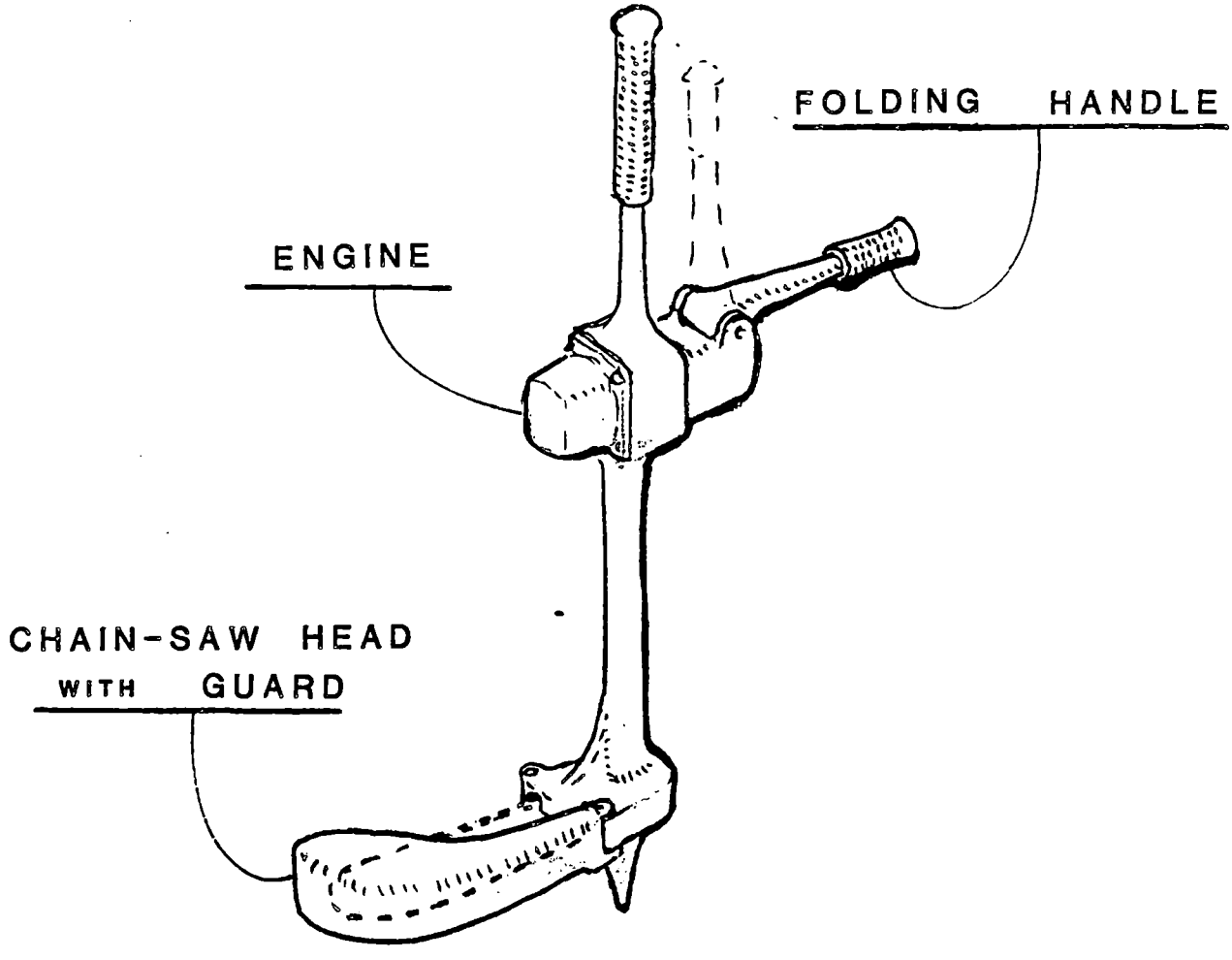
Drive

--- Desireable characteristics ---

* Good POWER to WEIGHT ratio.
* Low reaction forces, because of high speed and small mass (inertia).
* Centrifugal clutch engages only at high speed.

--- Undesireable characteristics ---

* The ultra-light weight engines are not sturdy enough for sustained heavy-duty service.
* Small light-weight rotary mass does not have enough inertia to permit overload and lugging.



CHAIN-SAW ON EXTENDED TORQUE-TUBE

Figure 12. The Chain-saw on Extended Torque-Tube is placed on the ground at the base of a tree and forced through the stump by pulling on the horizontal folding-handle, while the left hand supports the tool in an upright plane.

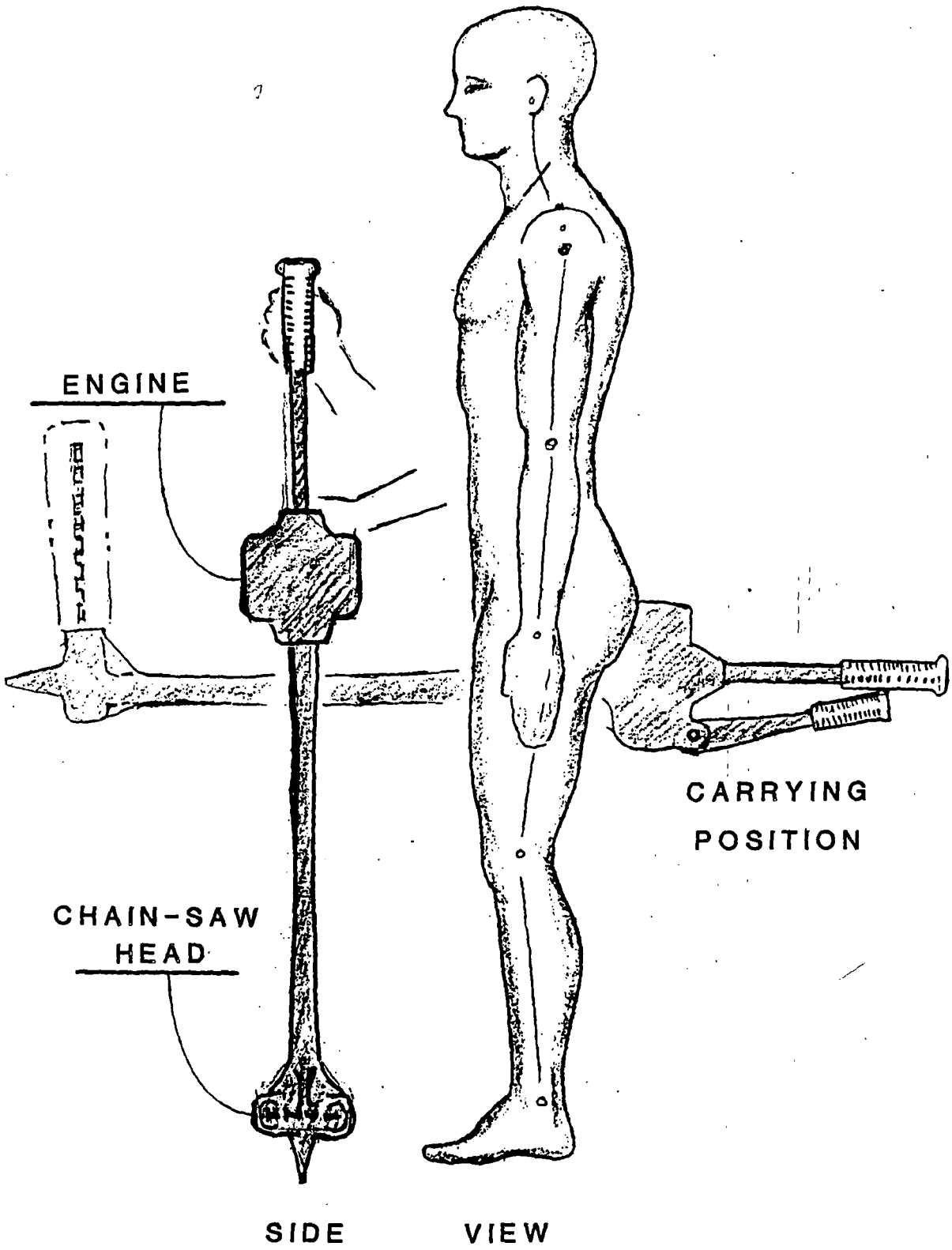
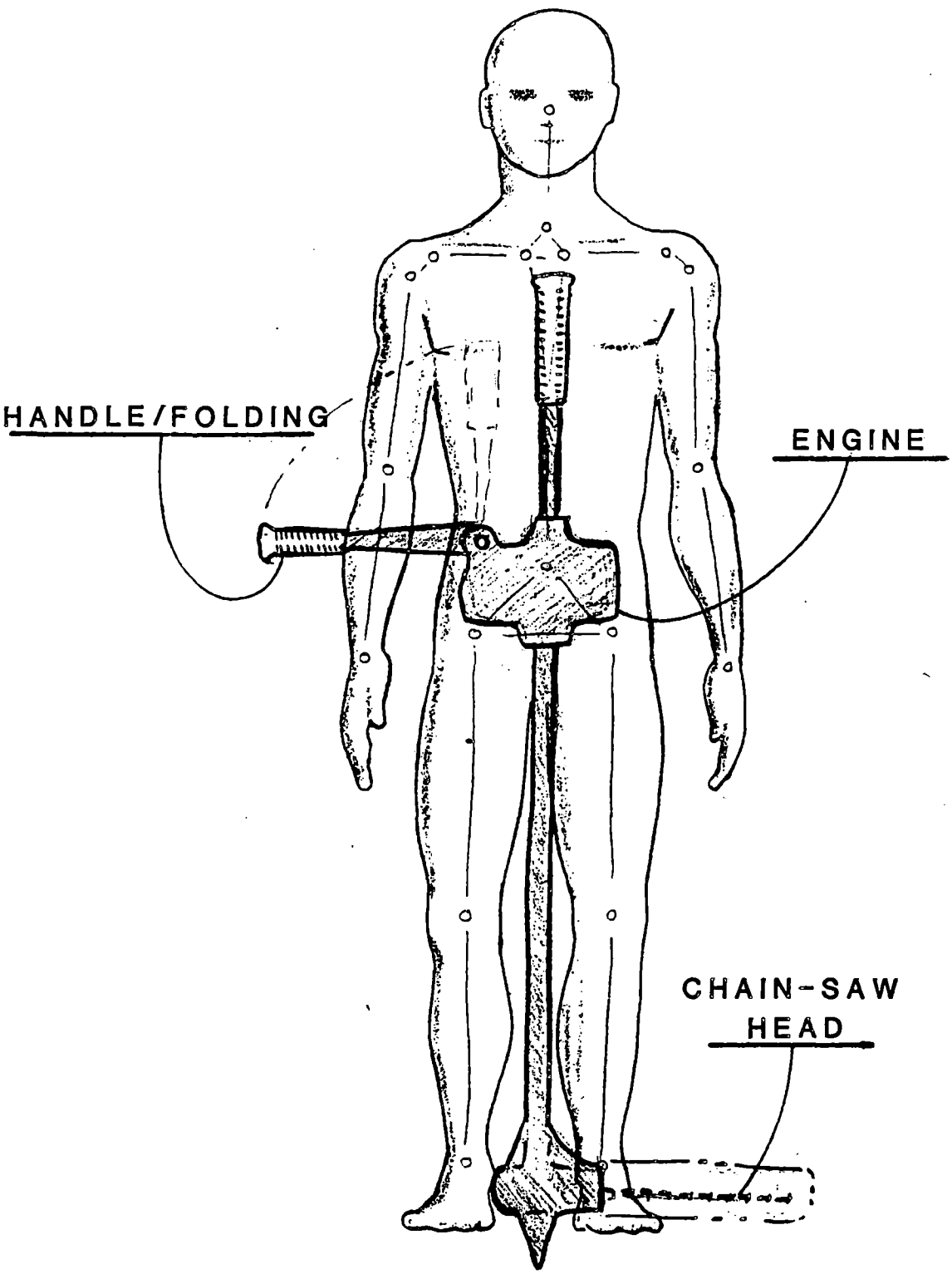


Figure 13. The Chain-saw on Extended Torque-Tube can be carried comfortably, and used for limbing and bucking.



FRONT VIEW

CHAIN-SAW ON EXTENDED TORQUE-TUBE

Figure 14. The Chain-saw on Extended Torque-Tube allows the sawyer to work in an upright position, but two hands are required to operate the tool.

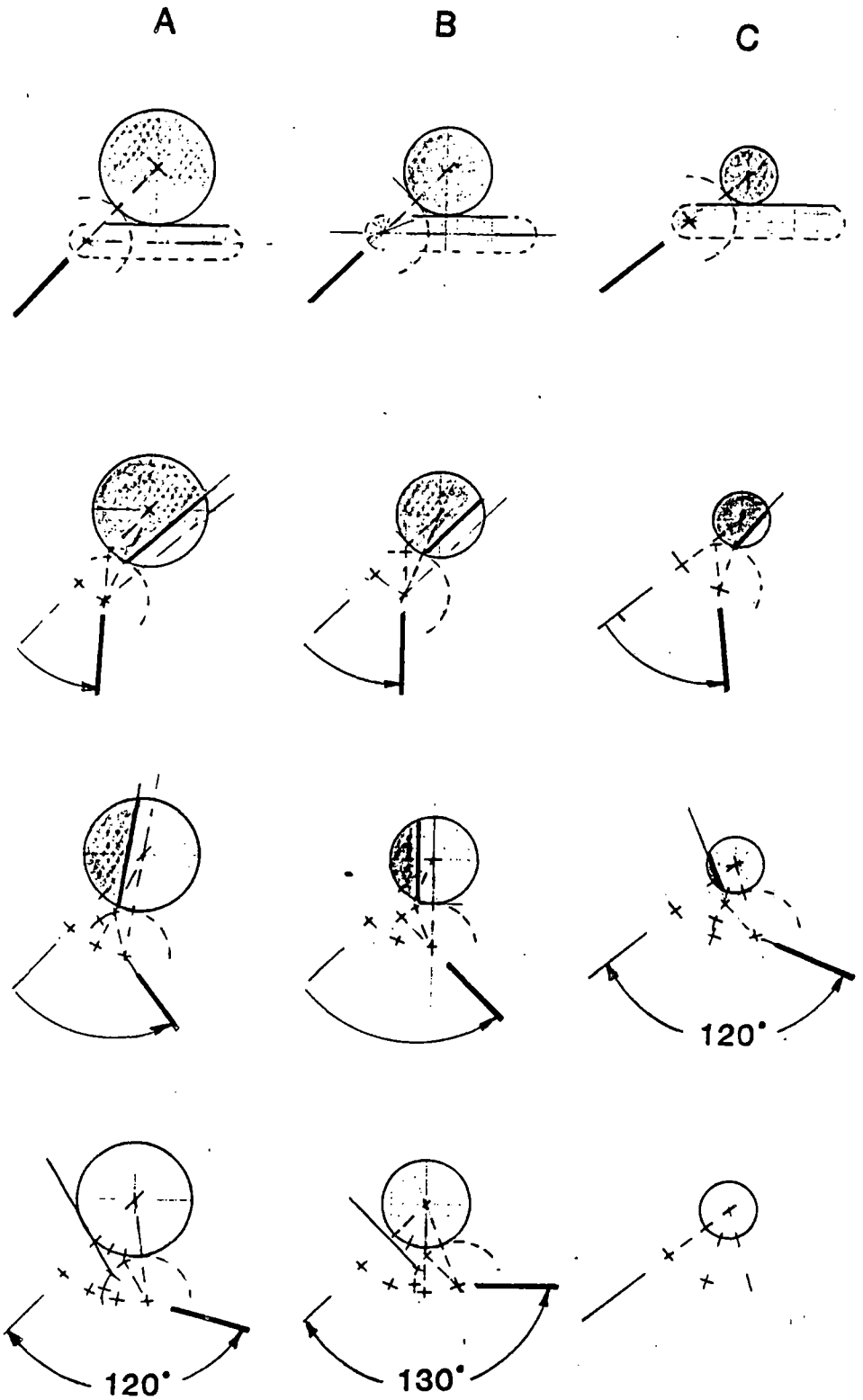


Figure 15. A standard-bar chain-saw handle must move approximately 120° around a work piece to make a cut when the fulcrum to pull the cutting-chain through a part is the spiked heel.

CHAIN-SAW on LONG-REACH ARM:

Description: The chain-saw cutting-head mounted to the end of a long-reach jointed-arm would be indirectly driven by a backpack mounted internal-combustion engine, with the power transmitted to the cutting-head by a round impregnated-fabric cable (similiar to those commonly used many years ago to drive dental drills). The head would be counter-balanced by springs to relieve the load upon the sawyers arm, and the cutting-bar would be positioned so the sawyer would push, rather than rotate, the cutter through the trunk, or reach around the trunk to make a backcut. Ideally the tool could be controlled with one hand, so the opposite hand could be used to support and/or guide the falling stem.

Cutter

--- Desireable characteristics ---

* Light weight head.
* Low inertia of moving mass.
* High speed / low torque.
* Well developed technology.
* Maintenance is simple.
* Relatively low-cost components.
* Very short bars can be used.

--- Undesireable characteristics ---

* The cutting chain produces a wide kerf.
* Chain-bar lubrication is required.
* Small stem can pinch the bar.
* The HEAD to ARM angle would be difficult to change.

CHAIN-SAW on LONG-REACH ARM (cont.)

Drive

--- Desireable characteristics ---

* Good POWER to WEIGHT ratio.
* Flexibility of design.
* Flexibility of movement.

--- Undesireable characteristics ---

* Potential loss of efficiency due to grease or oil contaminating the round impregnated fabric belt.
* Not a standard commercial product.

Ergonomics

--- Best features ---

* Sawyer stands in an upright position.
* Cutter-bar may be positioned to use the forward thrust of the sawyer leg muscles to force the tool through the trunk.
* The cutter may be raised/lowered and twisted.
* The cutting-head can be counterbalanced to limit the load the sawyers arm must carry and move.
* The cutter may be operated with one hand/arm.

--- Least desireable features ---

* One hand/arm is restricted to holding, guiding, and supporting the cutting head at all times.
* Limited movement.
* May be dificult to use for bucking.
* Difficult to start or adjust upon the back.
* Difficult to set aside

Personnel Environment

--- Desireable characteristics ---

* Increased leverage will reduce the kick-back force.

--- Undesireable characteristics ---

* Vibration transmitted to back and arm may be irritating and troublesome.
* High noise level near head and shoulders.
* Engine exhaust fumes near face.
* Fuel and oil leaking from the backpack could irritate the skin on back, hips and legs.
* Difficult to escape in an emergency.

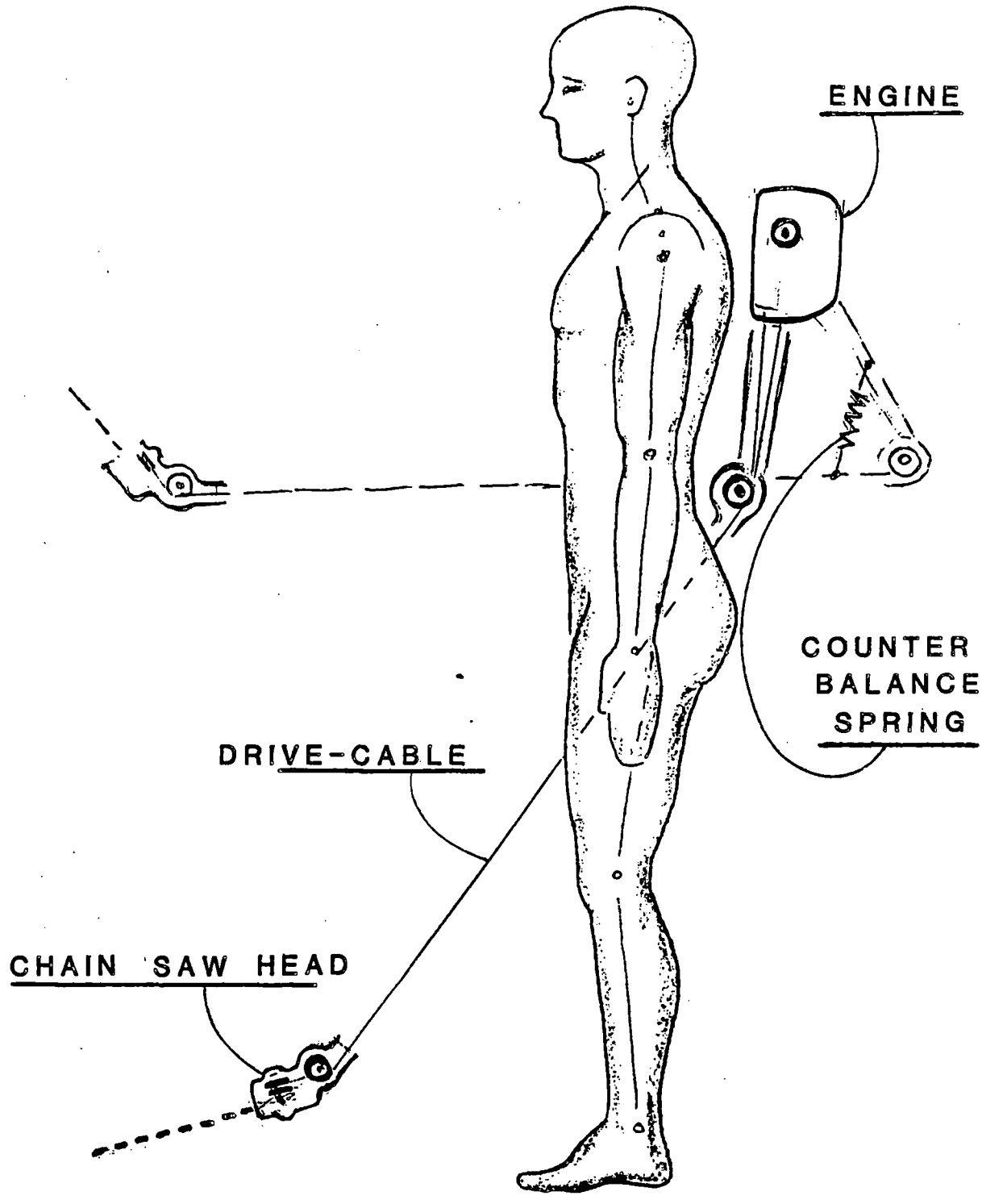
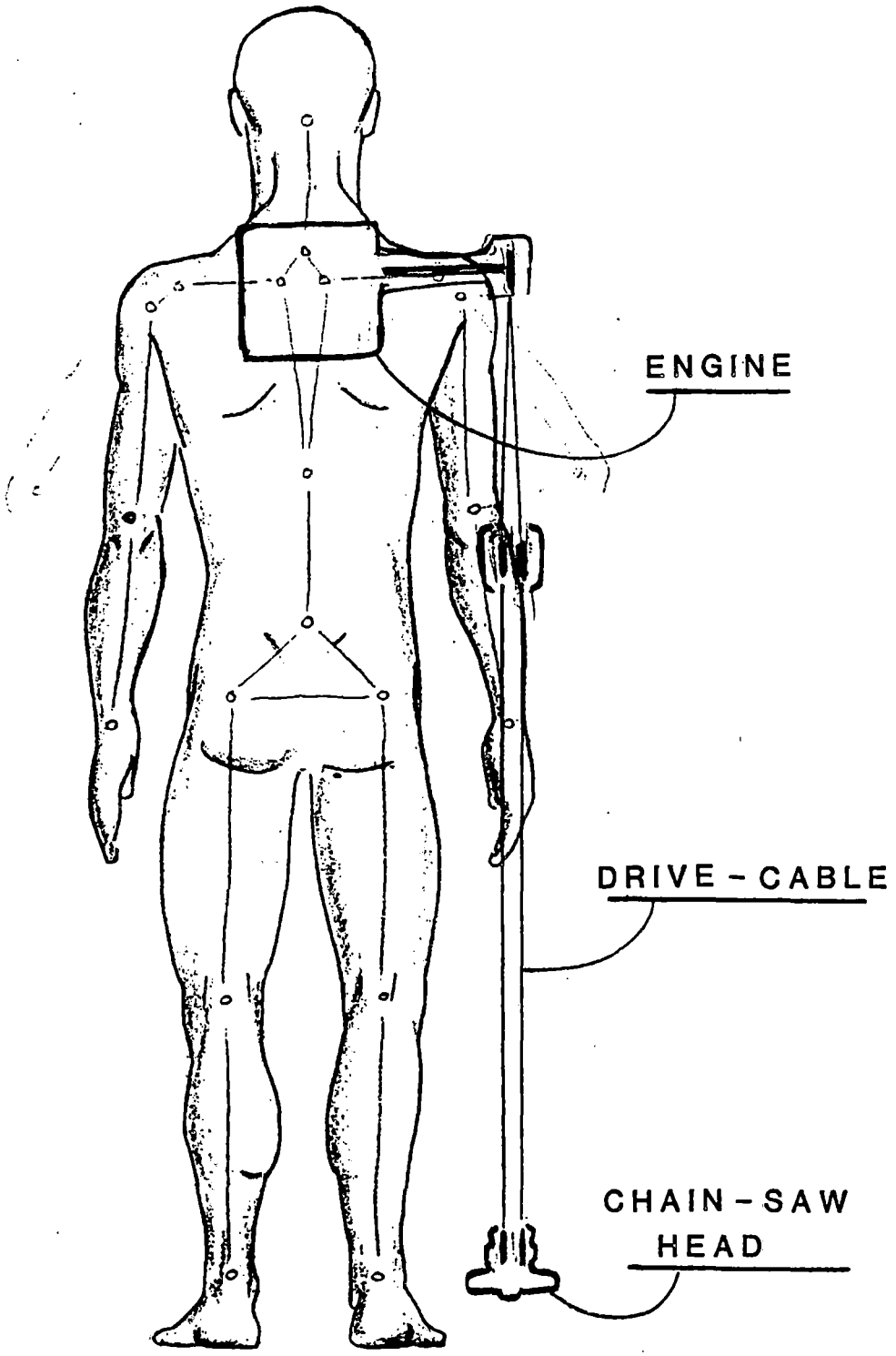


Figure 16. Counterbalance Springs on the Long-Reach Arms reduces the weight which must be supported by the Sawyer's arm.



BACK VIEW
CHAIN-SAW ON LONG-REACH ARM

Figure 17. The Long-Reach Arm can be fabricated with movement to permit the head to be twisted for limbing and bucking.

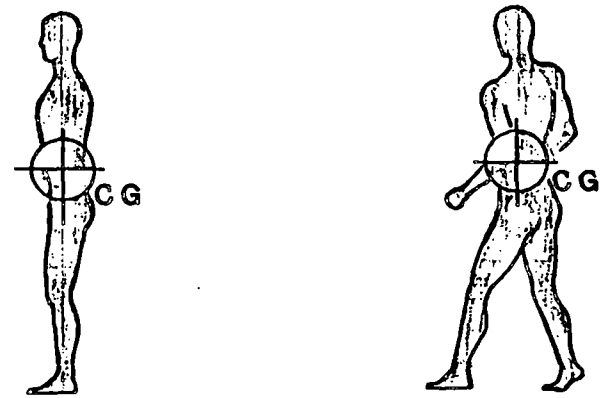


Figure 18. The body CENTER of GRAVITY (CG) and major AXIS of ROTATION (AR) is a point just above the hips and just forward of the spine.

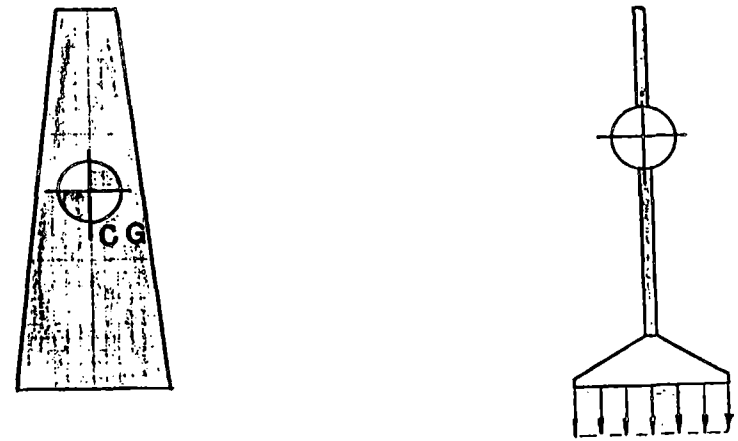


Figure 19. The body represented as a truncated cone, or a staff and pedestal, is a simple and effective way to show how different loads in various positions effect the carrier.

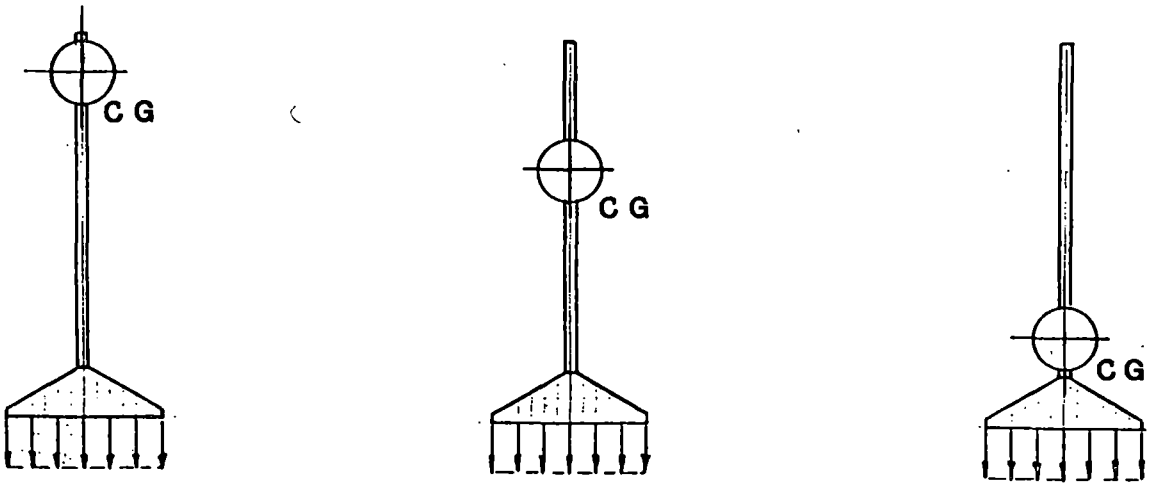


Figure 20. The height of a load does not effect the static stability of a body.

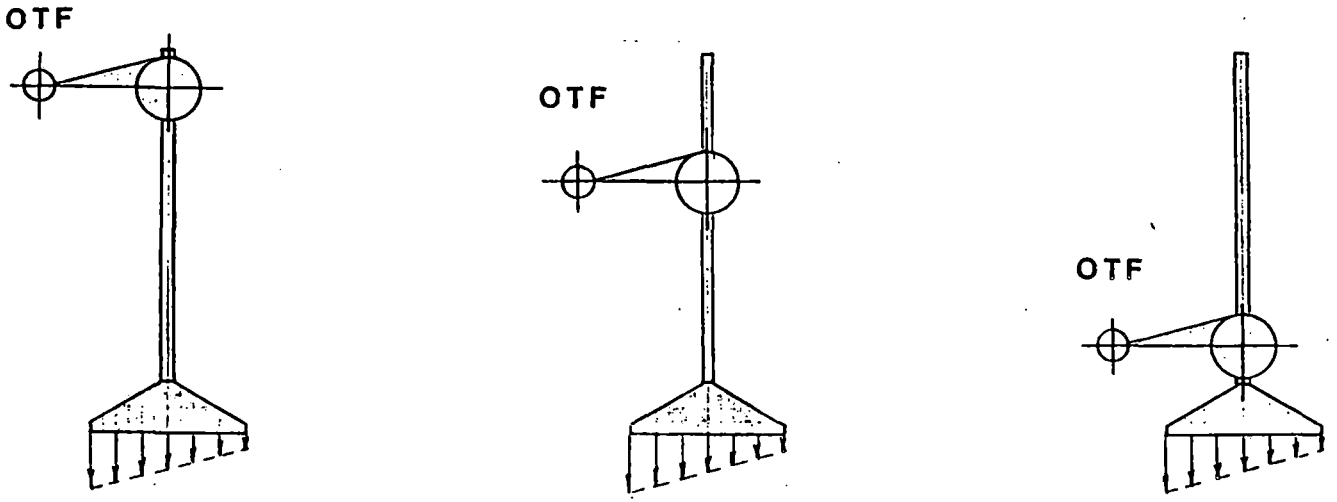


Figure 21. The height of an eccentric load does not effect the static stability of a body, if the overturning moment of the weight does not exceed the base reaction forces.

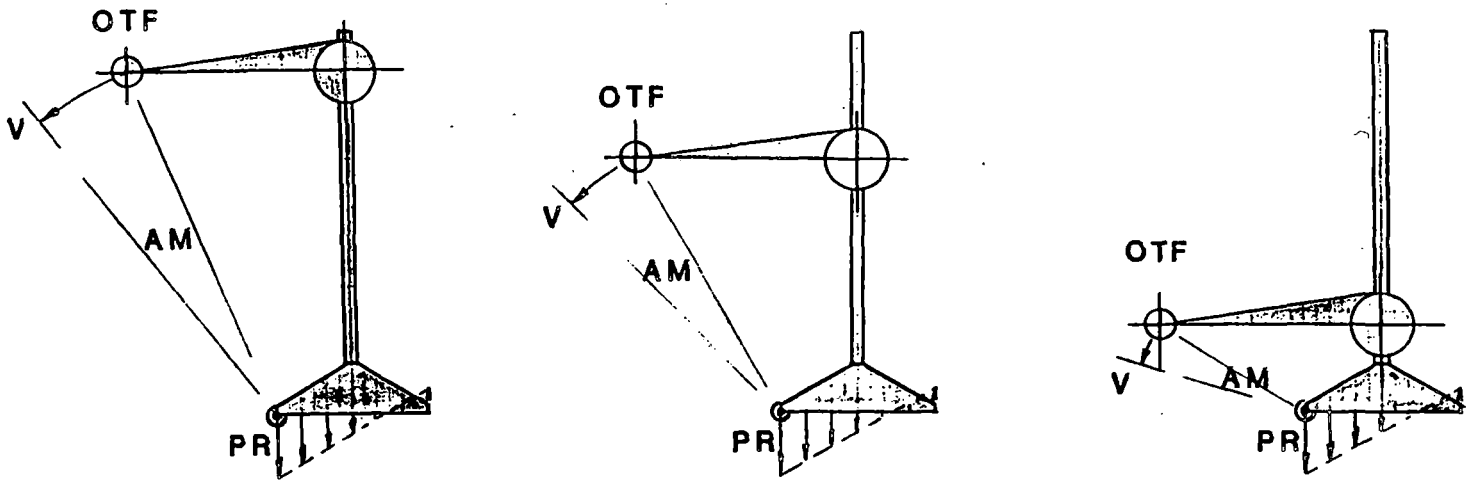


Figure 22. The ARC of MOVEMENT (AM) and VELOCITY (V) are proportional to the distance between the OVERTURNING FORCE (OTF) and the POINT of ROTATION (PR).

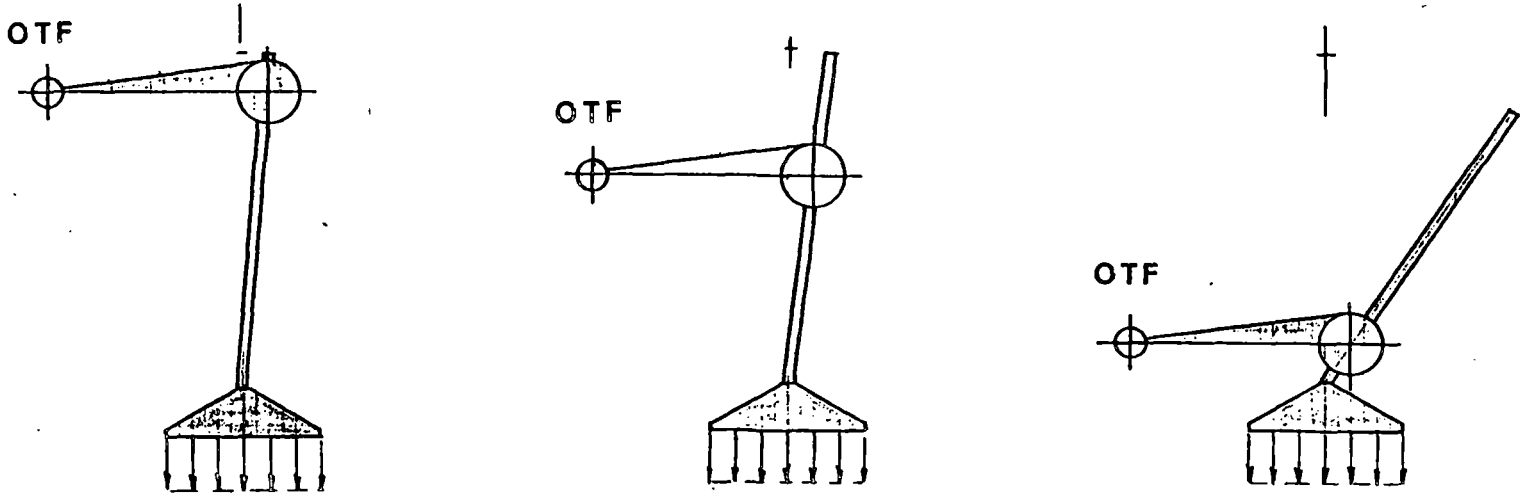


Figure 23. Uniform force distribution to a pedestal base can be accomplished by moving the staff from true vertical.

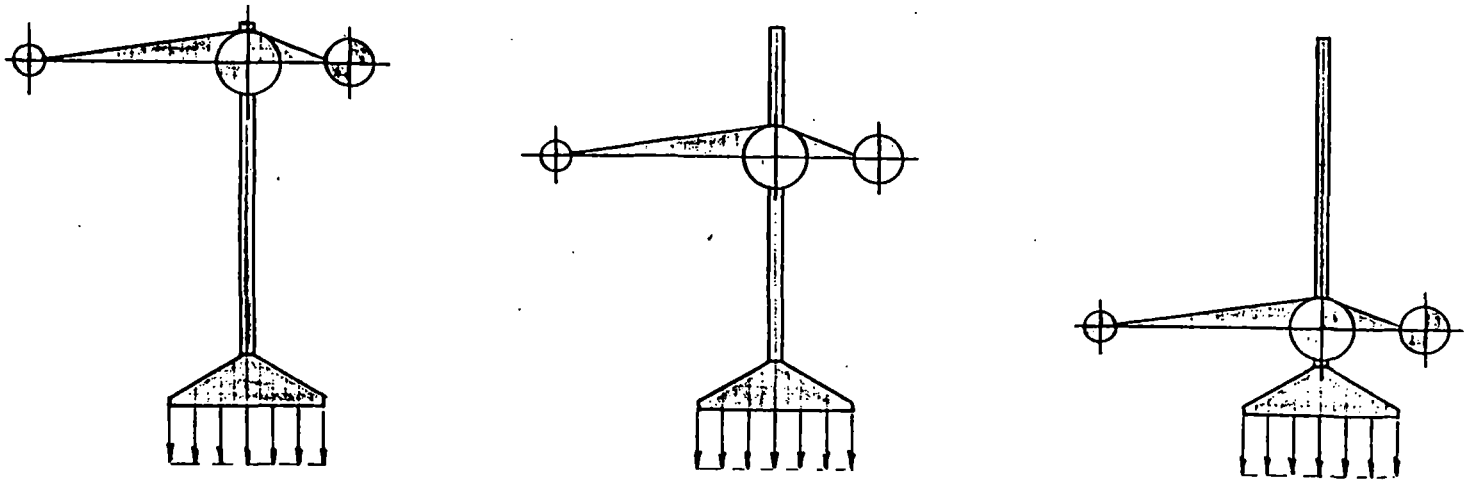


Figure 24. Uniform force distribution to a pedestal base can be accomplished by redistributing the eccentric weight, or adding counter-weights.

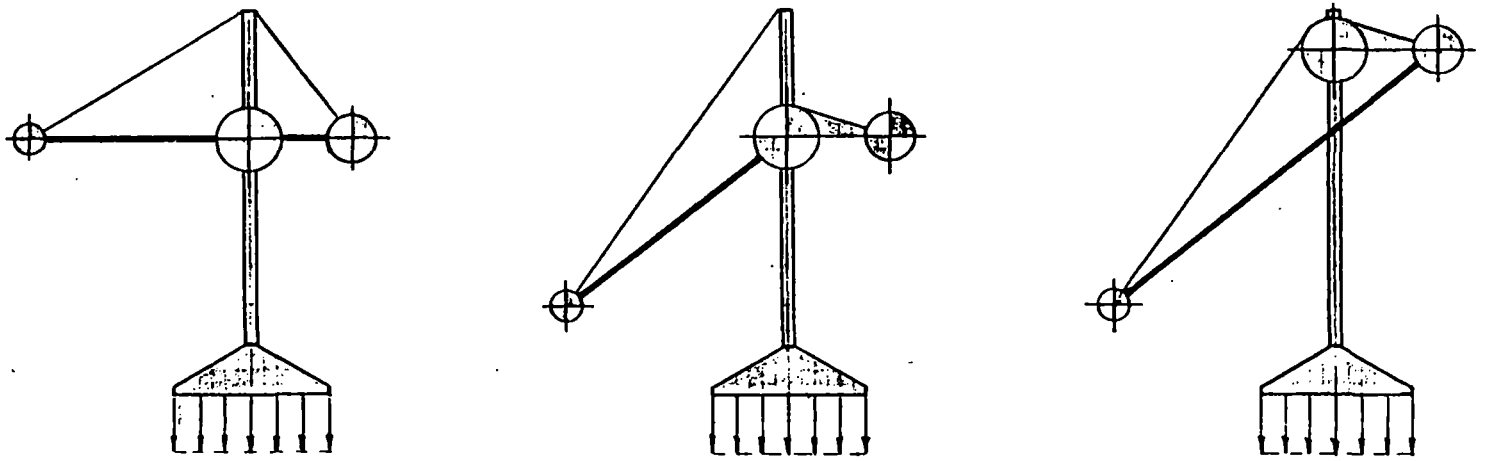


Figure 25. Tension elements can be used to minimize the cross-sectional area of a cantilever-arm, and still achieve adequate stiffness,rigidity and strength.

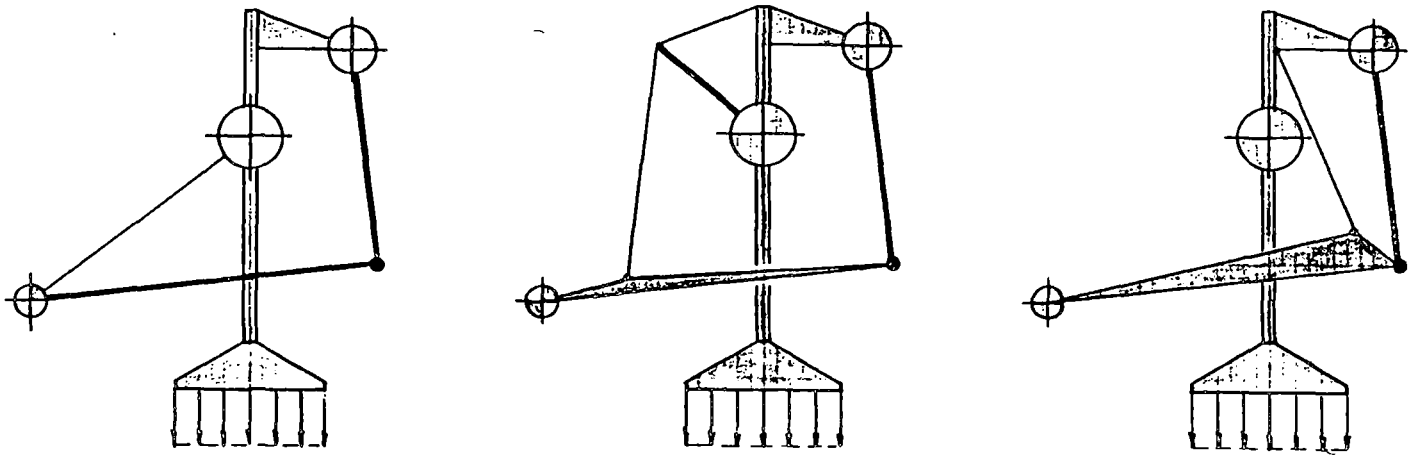


Figure 26. Placement of tension elements to support jointed and/or cantilever-arms, effects the arm size required to achieve the required stiffness, rigidity and strength.

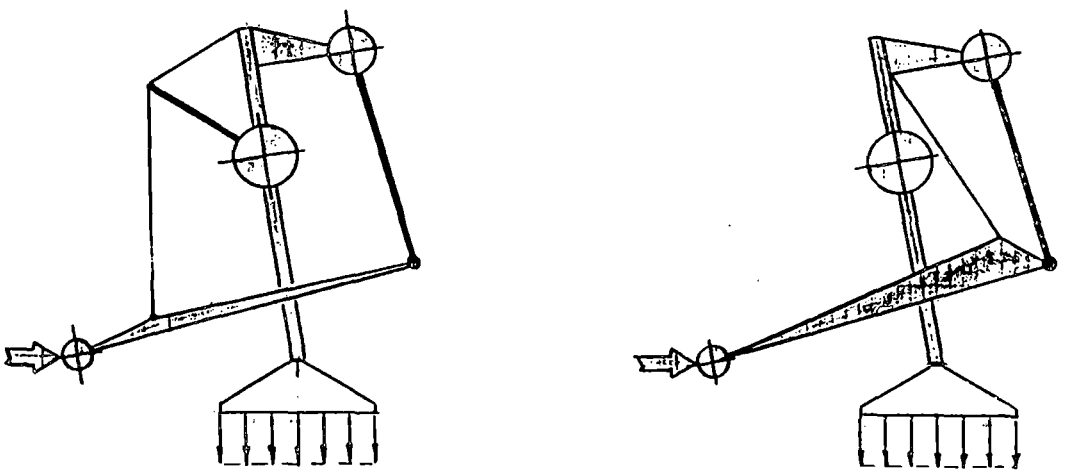


Figure 27. Uniform pedestal-force distribution (ground pressure) can be Maintained by moving the body Center of Gravity (CG) forward to compensate for external overturning-forces.

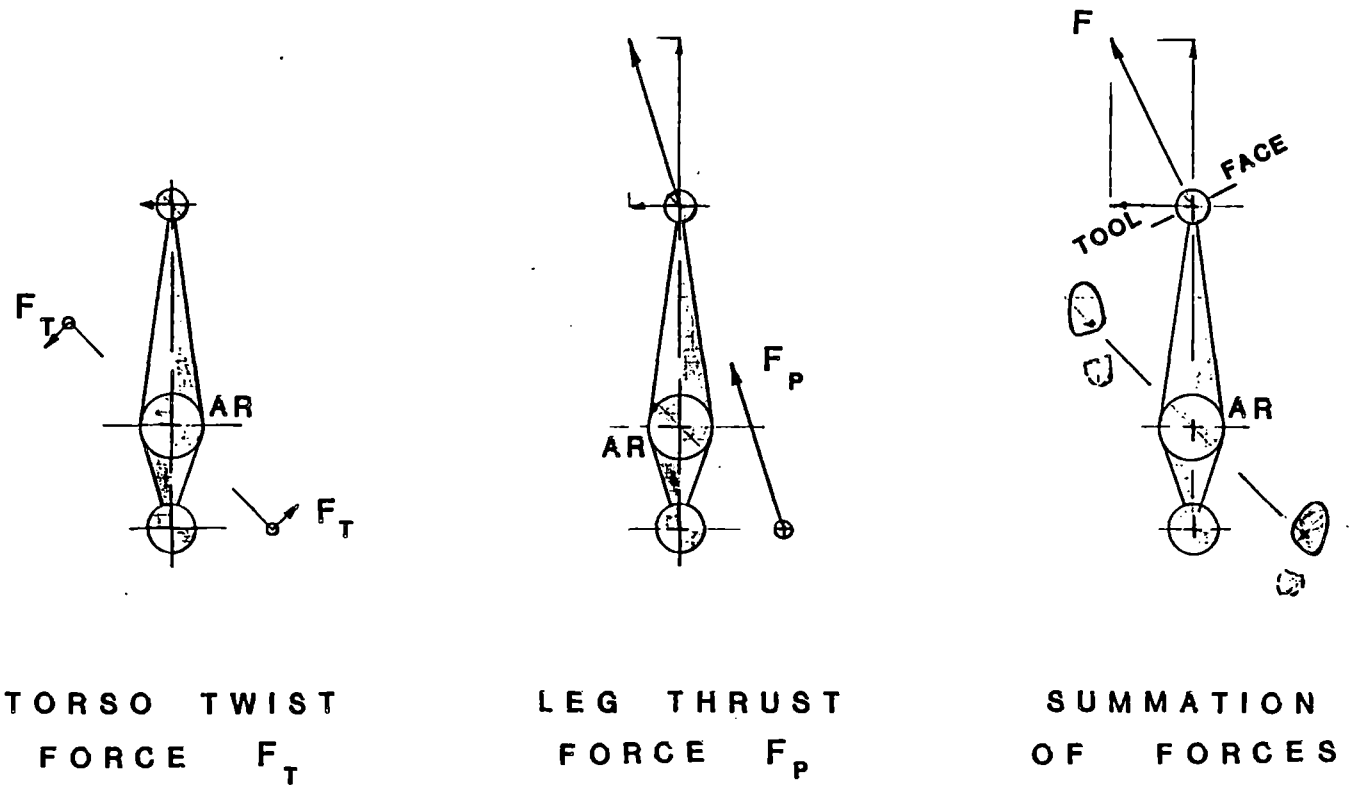


Figure 28. The preferred direction to thrust, or feed, the cutting tool should be determined by analyzing the summation of force around the bodies major Axis of Rotation (AR) to maximize use of the strongest muscles, the legs, and reduce the strain upon the less powerful.

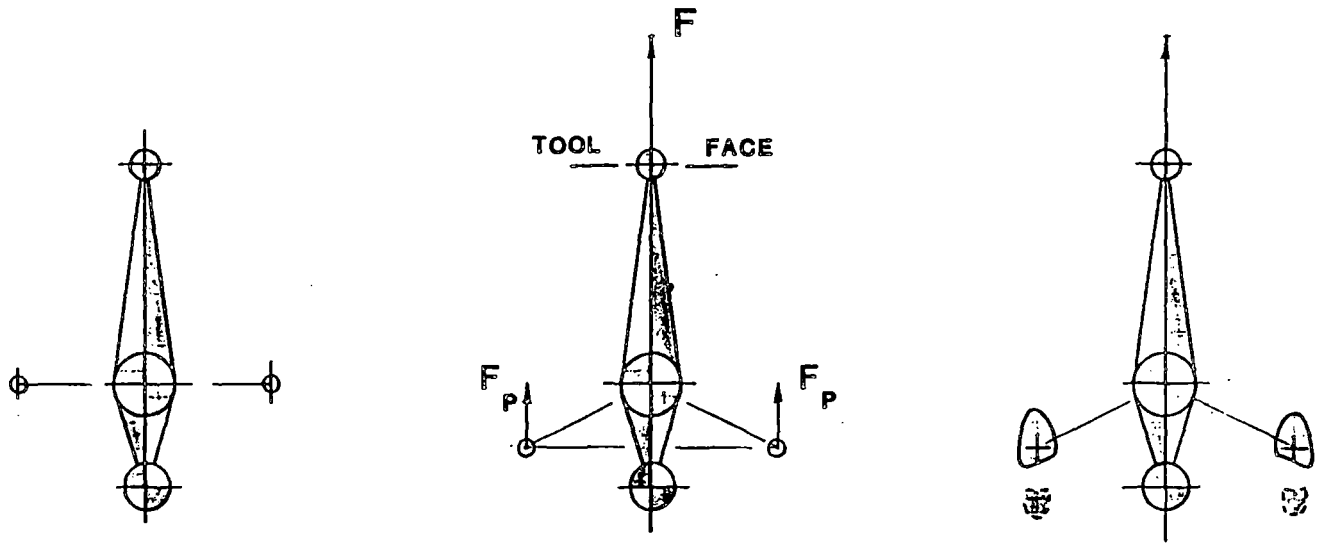


Figure 29. The ideal cutting tool orientation is directly in-front and parallel to the body, so all the thrust force to feed the tool is provided by the legs and no rotational strain is placed upon the torso.

BELT SAW in WISHBONE FRAME

Description: The belt-saw concept requires the development of an encapsulated-fabric corrogated-belt which would support edge-mounted chisel-shaped teeth. The belt, much like a steel band-saw blade, would be made with very high-tensil strength materials; such as graphite, armides, glass, etc., some of which exceed the tensile strength of steel several times. The belt would be encapsulated in abrasion resistant elastomers; such as ureathane rubber, to improve the wearability of the high-strength fabric, and to retain and support the cutting teeth. Corrogating the belt increases traction efficiency, track ability and reduces the minimum bend radius.

The saw-belt would be mounted in a wishbone shaped frame, with pulleys at each tip, and the drive engine at the apex. The saw frame would be pivoted on a two-legged support in a vertical plane, so the belt crossing the open-throat of the wishbone, cuts the tree as the saw is pivoted on the support. Proper placement of the support pivot is important so the belt cuts downward and through the stem. The cutting-motion and feed-force maybe accomplished with the sawyer stepping-down and/or pushing-down with the hand and body.

Cutter

--- Desireable characteristics ---

* Light weight
* Thin kerf, low power requirements
* Low inertia of moving mass.
* High speed/ low torque.
* No lubrication required.
* Cutter difficult to pinch.
* Belt would be sheathed and protected when not cutting.

--- Undesireable characteristics ---

* Not currently manufacturered.
* High cost to develope.
* Bucking and delimbing may be difficult.
* Ground height adjustment difficult.

BELT-SAW in WISHBONE FRAME (cont.)

Drive

--- Desireable Characteristic ---

* Low POWER to WEIGHT ratio.
* Low reaction forces, because of high speed and small mass (inertia).
* Centrifugal clutch would only engage at high speed.

--- Undesireable characteristics ---

* Ultra-light weight engines are not sturdy enough for sustained heavy-duty.
* Small light-weight rotary mass does not have enough inertia to permit overload or lugging.

Ergonomics

--- Best features ---

* The belt-saw would be well balanced with grip near center of gravity.
* Operation without stooping.
* Sawyer stands in an upright position.
* Cutting feed-force assisted by gravity.
* Only one hand required to operate.

--- Least desireable features ---

*

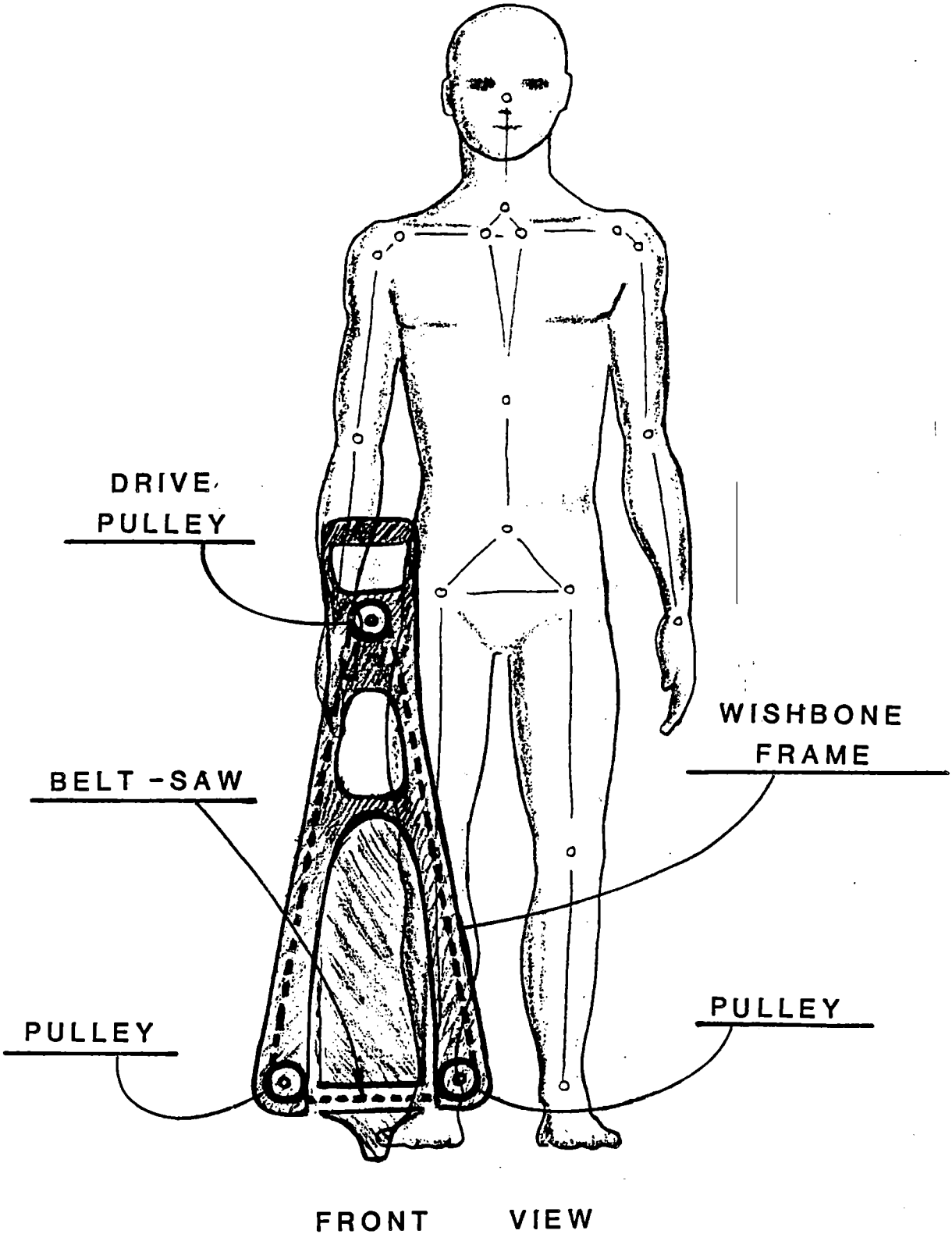
Personnel environment

--- good features ---

* The belt-saw can be easily set aside for comfort and safety reasons.
* Minimum kickback hazard.

--- Undesireable characteristics ---

* Vibration transmitted from the engine to the hand and arm can be irritating and troublesome.
* High engine noise level, close at hand.
* Gasoline fumes near the face.



BELT-SAW IN WISHBONE FRAME

Figure 30. The Belt-Saw is protected within the Wishbone "A" frame. The distance between the idler pulleys determines the tree cutting capacity.

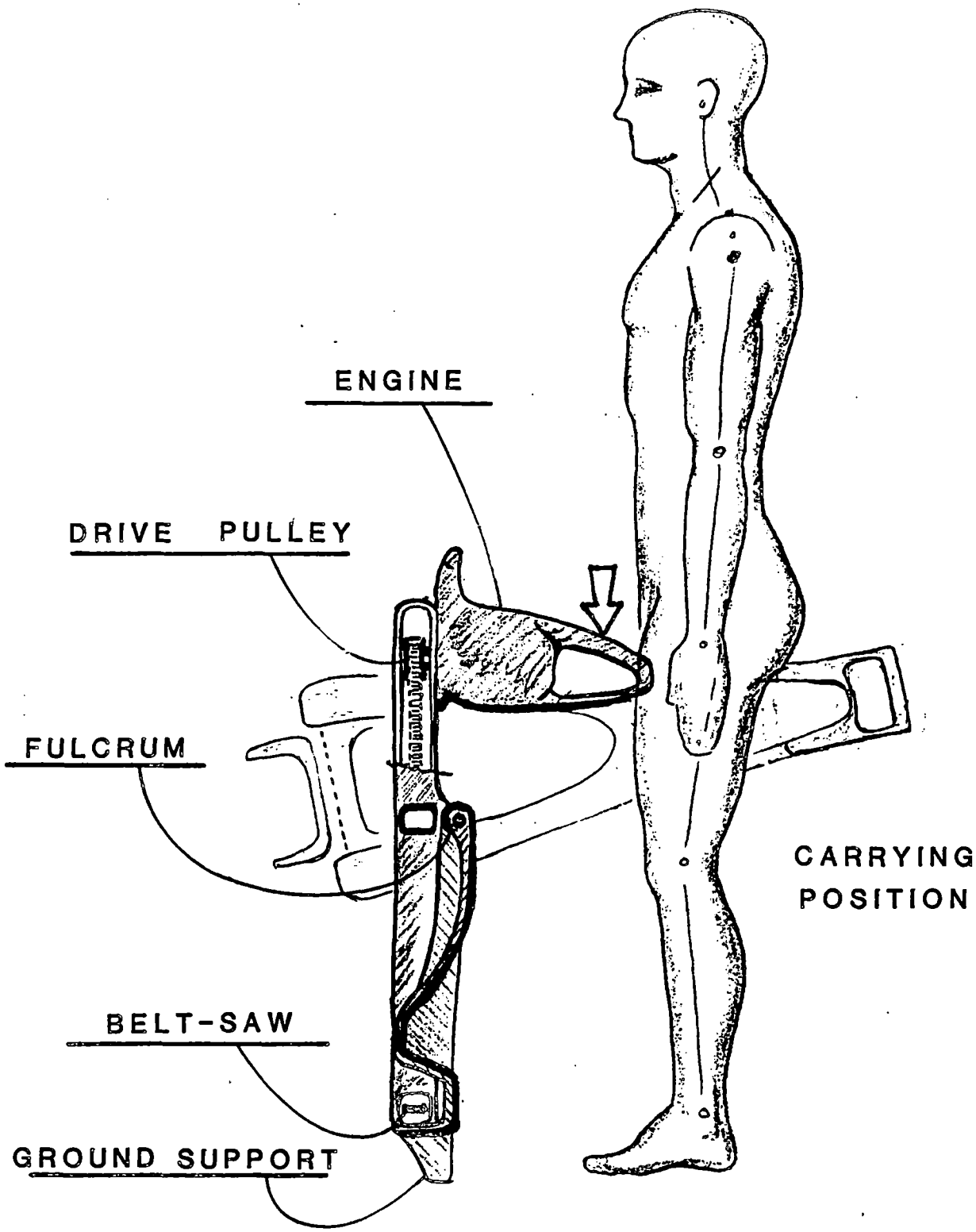


Figure 31. The Belt-Saw in Wishbone-Frame can be easily carried, and used by the sawyer in an upright posture.

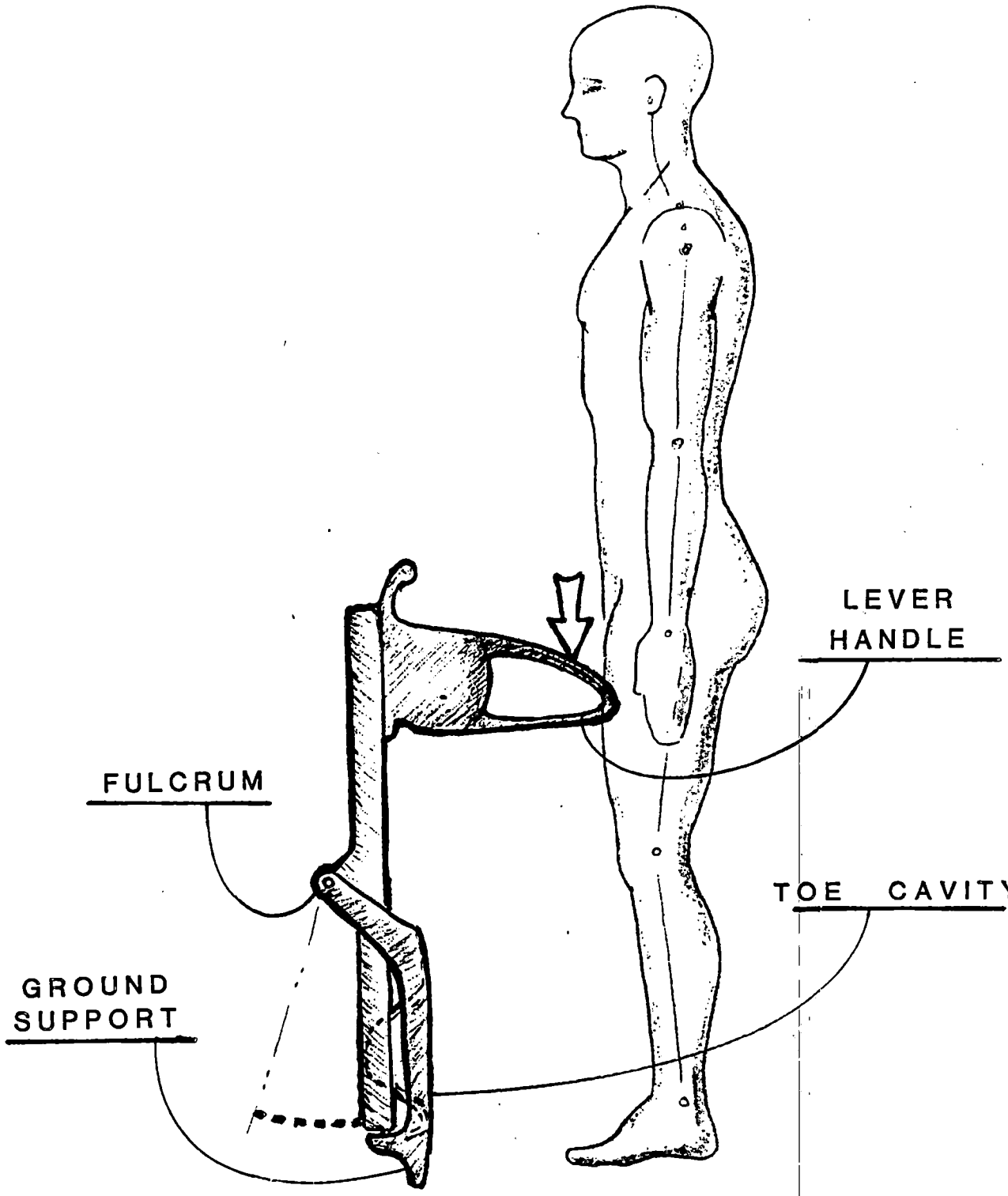
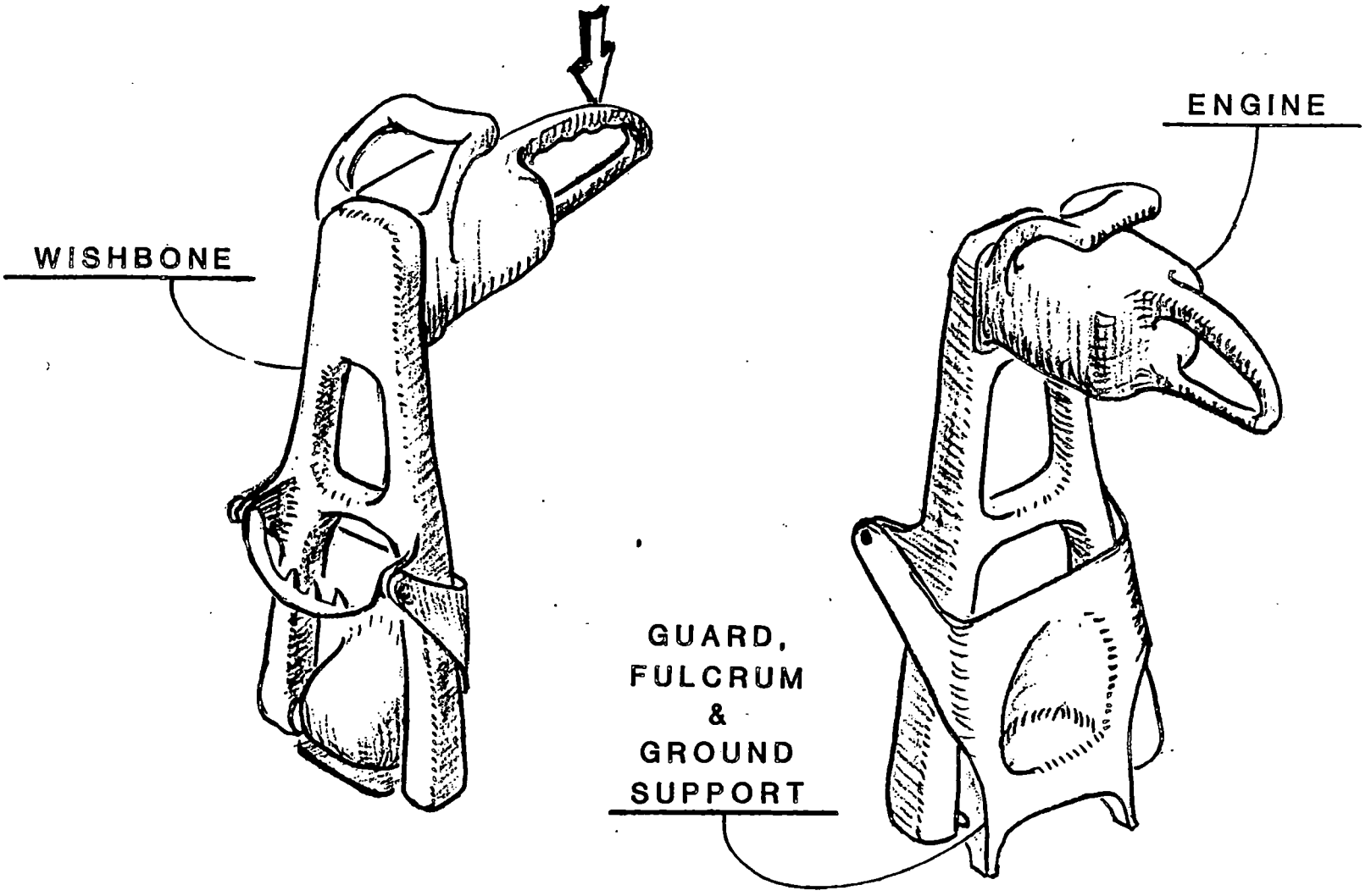
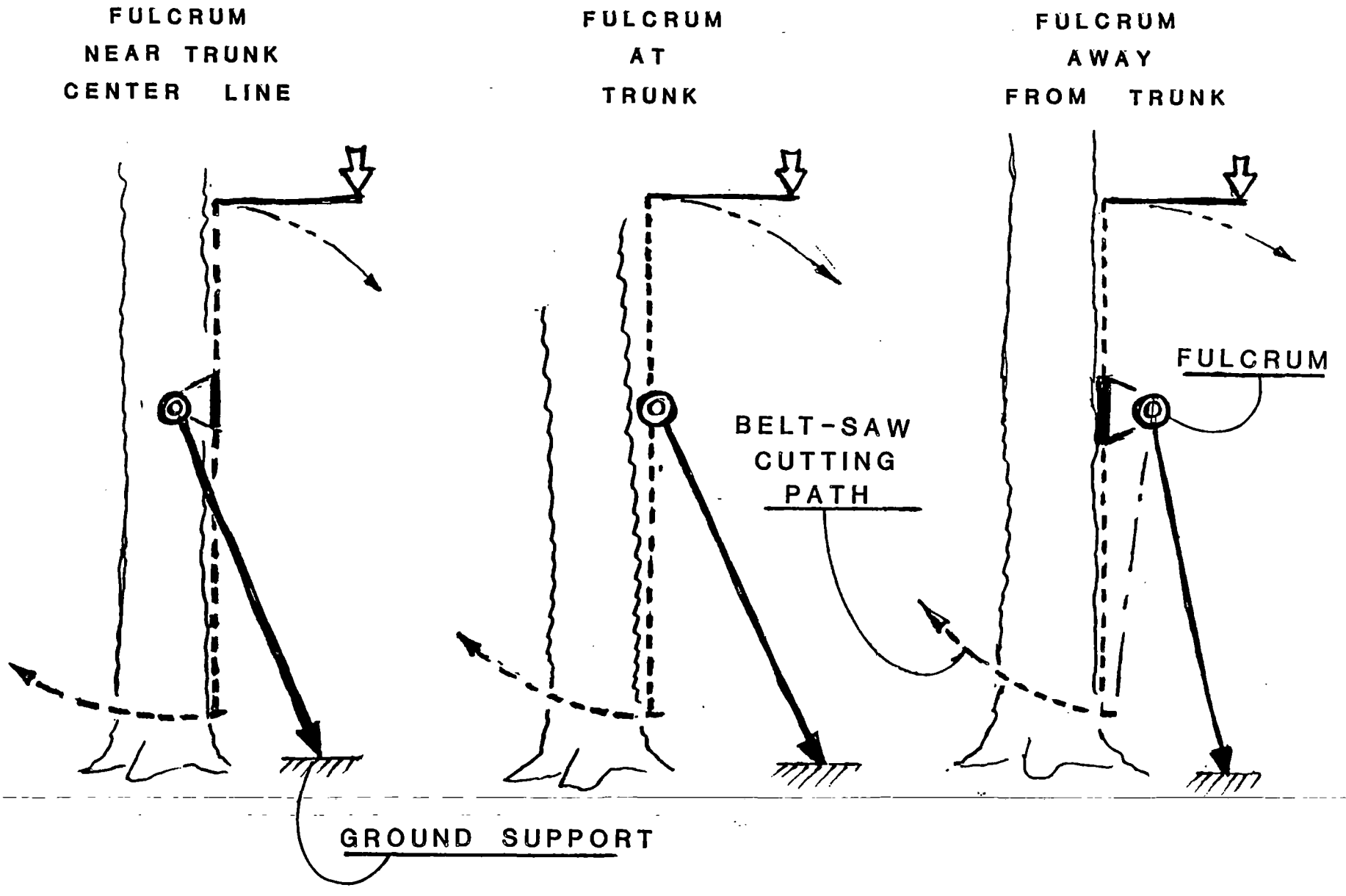


Figure 32. A downward thrust of the handle forces the belt saw into the tree trunk. Placing the foot into the toe cavity helps set the ground support reaction point.



BELT-SAW IN WISHBONE FRAME

Figure 33. The Belt-Saw is protected within the Fulcrum and Ground-Support frame, and exposed only when the downward force on the handle tilts the Wishbone "A" frame at the fulcrum.



MOTION DIAGRAM OF BELT-SAW IN WISHBONE FRAME

Figure 34. Locating the fulcrum of the Belt-Saw Wishbone frame close to the tree trunk center-line, causes the Belt-Saw to follow a horizontal-arc, so the tree can fall away from the sawyer.

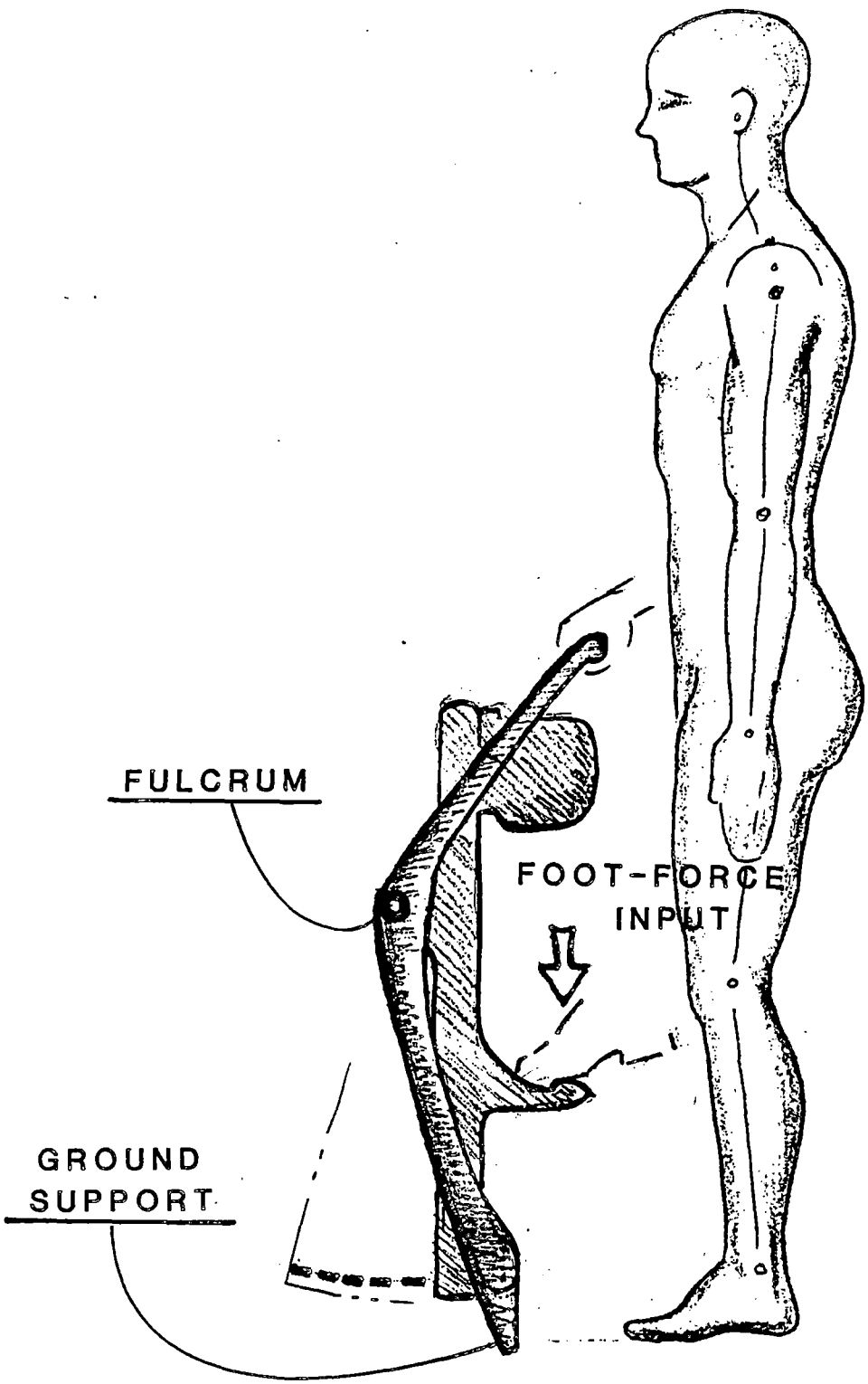


Figure 35. The force to move the Belt-Saw through the tree trunk is provided by the foot, when the handle is integrated into a common frame with fulcrum and ground support.

WIRE or CABLE SAW:

Description: The cutting wire or cable concept would use an encapsulated fabric-core of very high tensile-strength filaments, which would carry star shaped cutters strung upon the cable (wire) like beads. The star shaped cutting-beads would allow the moving cable to cut from any direction, create a very thin kerf, and develope very little drag.

There are many possilbilities for developing very different and unique, light-weight cutting devices using this concept. One concept would be very similiar to the belt-saw designs. But, the research, development and tooling costs would be very high and the market demand would have to be very great and/or the volume extremely large to justify further pursuit of this idea.

CHAIN-SAW with BOW-BAR, modified for STIFF-LEG:

Description: The concept incorporates a standard chain-saw fitted with a bow-bar and special handle with a pivot arm, mounted near the center of gravity and parallel to the cutting-bar of the saw, which can rest into a support-knotch on the shin-section of the special "stiff-leg". The "stiff-leg", designed to pivot at the hip-bone socket when strapped to the sawyer's thigh, acts as a lever to force and guide the cutting bar through the stem being felled.

The very light weight "stiff-leg", constructed of very-high tensile-strength composites of graphite, arimids, boron, glass, etc., is strapped to the thigh and supported on the hips, so the natural downward movement performed by bending the knee and lifting the heel, provides the straight-line force to push the cutting-chain through the trunk.

The tool maybe carried about like a conventional chain-saw, used to buck and delimb, or set aside for comfort and safety when required. And, the hinged "stiff-leg" knee-joint may be unlocked to allow for natural movement.

CHAIN-SAW with BOW-BAR, modified for STIFF-LEG: (cont.)

Cutter

--- Desireable characteristics ---

* Light weight.
* Low inertia of moving mass.
* High speed / low torque.
* Very well developed technology.
* Maintenance is simple.
* Easy to repair.
* Relatively low cost components.
* Bow-bar least susceptible to being pinched.
* Best configuration for cutting brush and small diameter trees.
* The cutting chain is only moving when the engine RPM is high.
* Good tool for bucking and delimbing.

--- Undesireable characteristics ---

* The cutting chain produces a wide kerf.
* Chain-bar lubrication required.
* High torque engines required due to heavy bow-bar drag.

Drive

--- Desireable Characteristics ---

* Very good POWER to WEIGHT ratio.
* Low reaction forces, because of high speed and mass (interia).
* Centrifugal clutch engages only at high speed.

--- Undesireable characteristics ---

* The ultra-light weight engines are not sturdy enough for sustained heavy-duty service.
* Small light-weight rotary mass does not have enough inertia to permit overload or lugging.

CHAIN-SAW with BOW-BAR, modified for STIFF-LEG: (cont.)

Ergonomics

--- Best features ---

* Sawyer stands in an upright position.
* The chain-saw is well balanced with handle grip near the center of gravity.
* The unit may be used in any attitude.
* The tool is pushed through the stem.
* The strongest muscles, the legs, is used to do the work.
* The tool may be controlled with one hand.
* The tool is self-standing so the sawyer may have both hands available as required.

--- Least desireable ---

* Some movement restricted with "stiff leg" locked.
* Bucking and delimbing hindered by long handle.

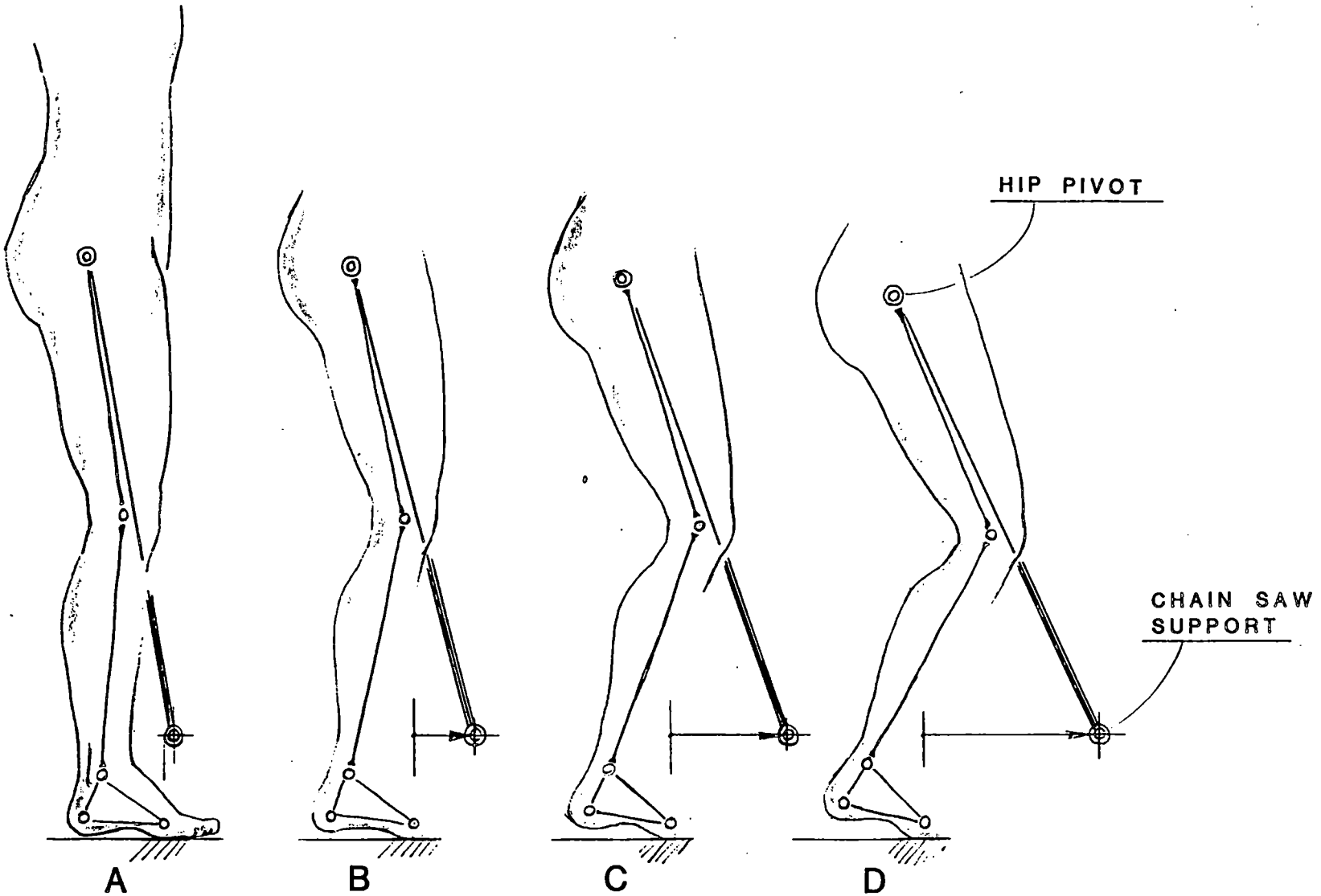
Personnel environment

--- Good features ---

* The chain-saw can be easily set aside for comfort and safety reasons.
* Engine noise and exhaust fumes are remote from sawyers ears and nose.

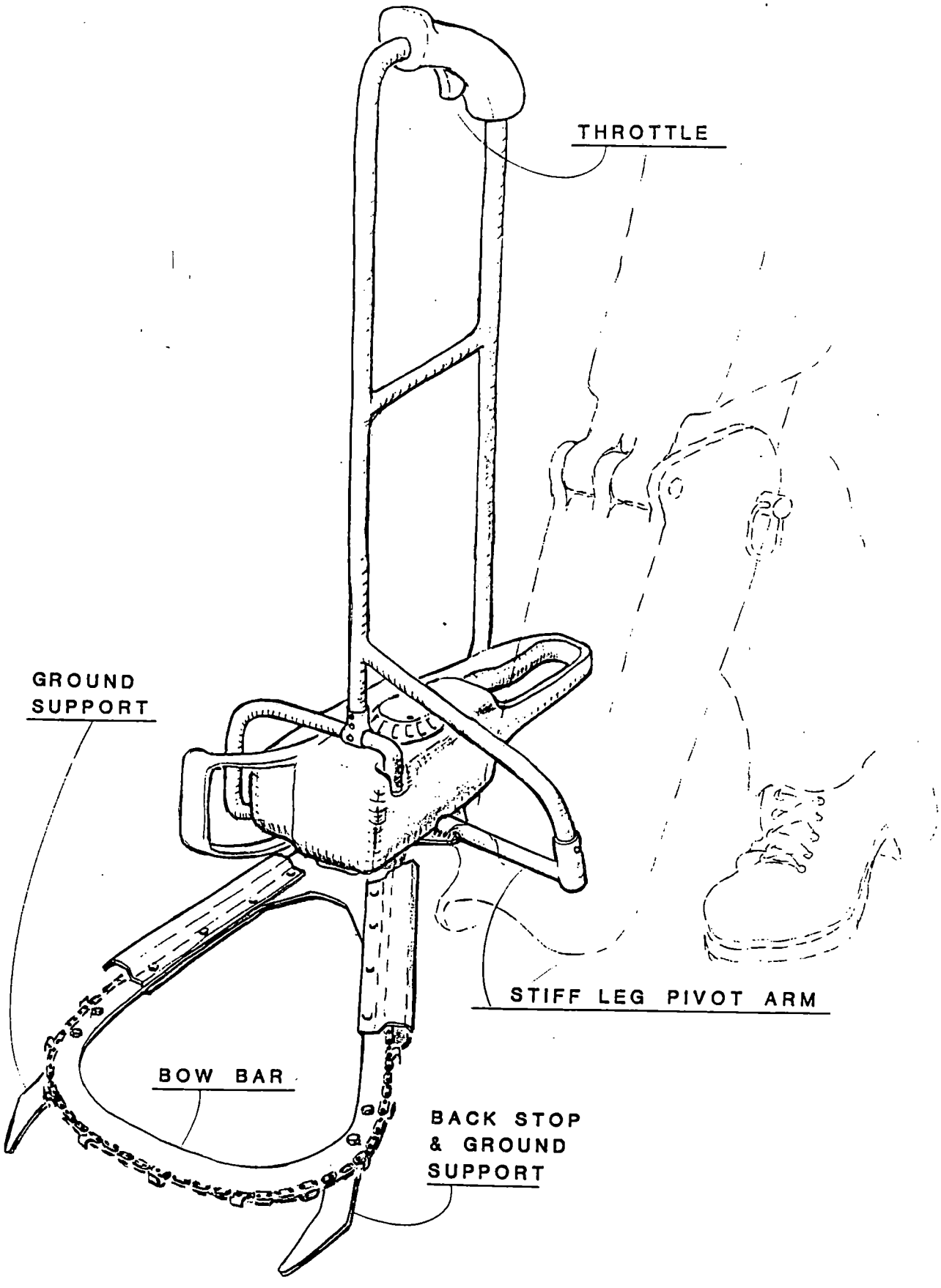
--- Undesireable characteristics ---

* Vibration transmitted to the thigh may be irritating.



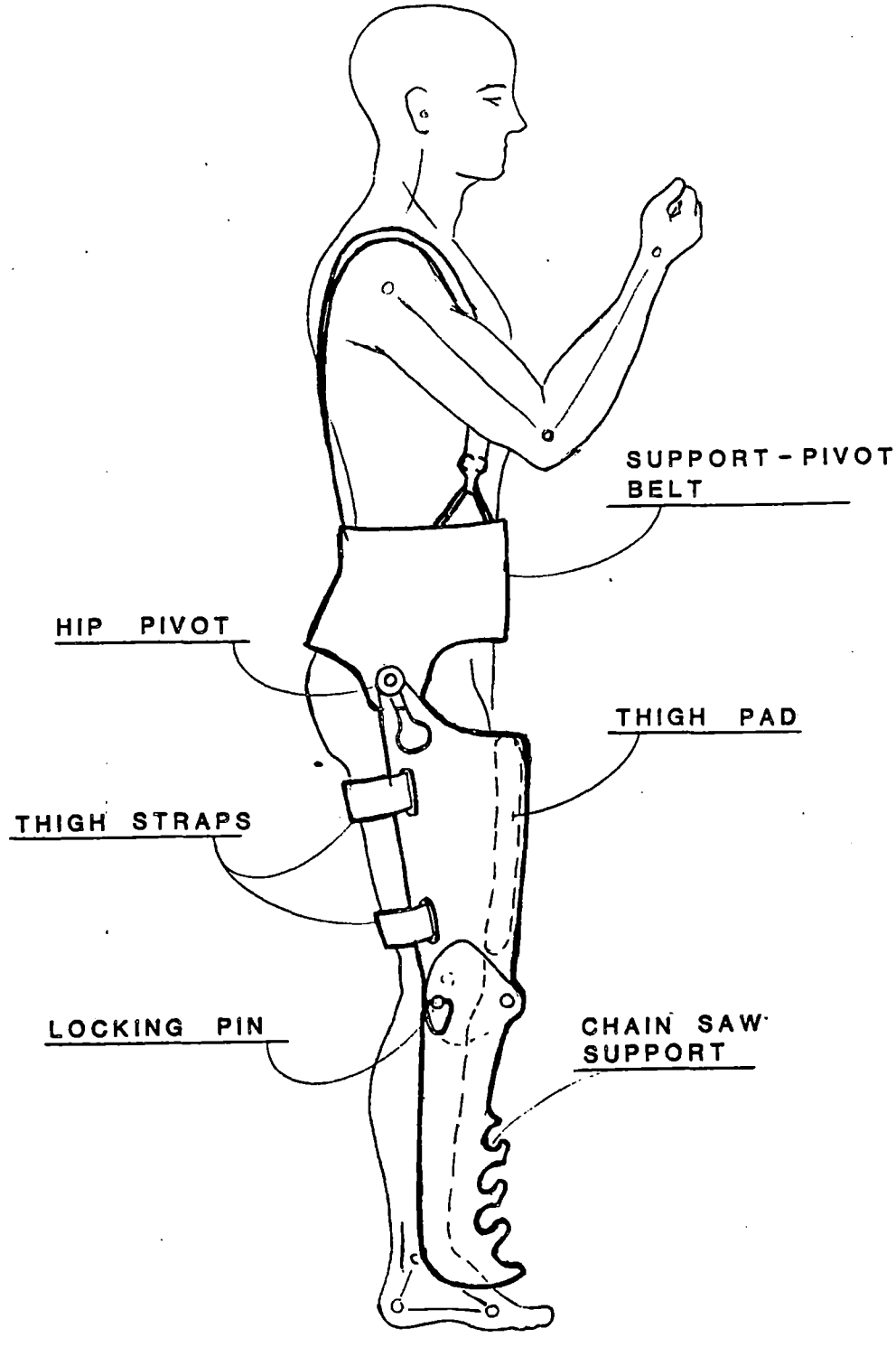
STIFF-LEG MOTION DIAGRAM

Figure 36. The natural movement to lower the body, bend the knee and raise the heel produces a straight-line motion, near the ground, for a point [CSS] (Chain-Saw Support), at the end of a leg extension pivoted at the hip-joint.



BOW-BAR CHAIN-SAW MODIFIED FOR STIFF-LEG

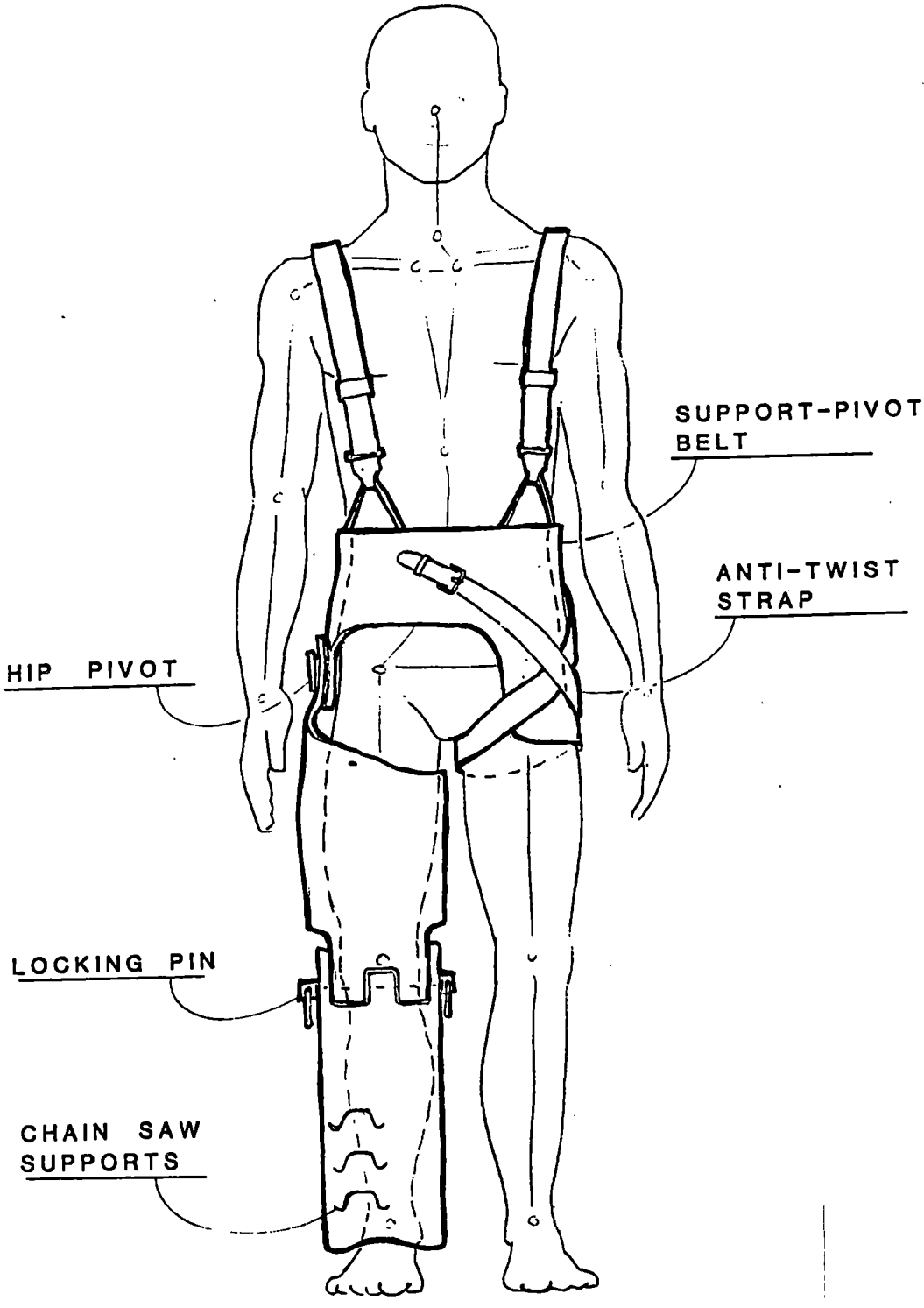
Figure 37. With the Chain-Saw Pivot-Arm in the Stiff-Leg Saw-Support-Knotch the Sawyer may release the handle and allow the Bow-Bar to rest upon the Ground-Support-Horns. The Sawyer now has both hands free.



RIGHT SIDE VIEW

STIFF-LEG

Figure 38. The Stiff-Leg extension is a lever to produce a forward thrust near ground level, when the body is lowered and the knee bent. Reaction forces are on the Thigh-Pad and Hip-Pivot.



FRONT VIEW

STIFF-LEG

Figure 39. The Pivot-Support-Belt fitted with Anti-Twist-Strap resists the reaction force applied to the Hip-Pivot. Pulling the Locking-Pin improves mobility when work is not being preformed by allowing the lower leg extension to move freely.

SLED-MOUNTED PORTABLE POWER-UNIT and TOOL CARRIER

Description: The sled-mounted portable power-unit and tool-carrier would incorporate a medium-speed continuous-duty gasoline-fuel engine direct driving (a) hydraulic pump(s), which would be the central power source for operating a variety of tools and devices carried in or on the sled. The tools may include: WINCH(es); to move the sled from place to place; to assist in bunching, moving and yarding felled-material; or perform other heavy-stress service work, TOOLS; very light-weight high-speed hydraulic-motor driven chain-saw(s) for limbing, bucking, lopping, etc.; very light-weight hydraulic-shear(s) for falling stems smaller than 2½-inch diameter; Medium-weight moderate speed hydraulic-shear(s) for falling trees up to six-inch in diameter.

Electrical-powered hand-tools available for tree falling are limited to chain-saw tools, which are NOT as light-weight, powerful, safe and inexpensive as the hydraulic chain-saws; and electric winches are not as versatile or compact as hydraulic winches, therefore portable electric-generator power-units are not considered a viable option.

Cutting Tools

--- Desireable characteristics ---	--- Undesireable characteristics ---
# Hydraulic-motor driven chain-saw tool	
* Very light-weight and high-power.	* Hydraulic hoses from the power-unit.
* High-speed.	
* Easily integrated into a long-reach handle.	
* Quite, very low-vibration.	
* Instant stop and start.	

SLED-MOUNTED PORTABLE POWER-UNIT and TOOL-CARRIER (cont.)

Hydraulic-shear for stems smaller than 2½-inches.

* Light-weight.
* Good-speed. (relative to circuit and pump size)
* Very safe.
* Easily integrated into a long-reach handle for comfortable one-hand operation.
* Very quite, no vibration.
* Reliable, minimum maintenance.
* Minimum lubrication.
* Hydraulic hoses from the power-unit.

Hydraulic shear for stems smaller than 6-inch diamater.

* Moderately heavy.
* Good speed. (relative to circuit and pump size)
* Very safe.
* Very rugged, reliable, minimum maintenance.
* Minimum lubrication.
* very low stumps.
* Both-hands completely free.
* Weight too great for moving about to fall all size stems.
* Hydraulic hoses from the power unit.

Drive

--- Desireable characteristics ---

--- Undesireable characyrtistics ---

Medium-speed (1800-4000 rpm) continuous-duty gasoline-fueled engine.

* Reliable, good service life, low maintenance.
* Constant, moderate speed.

* Weight per unit of power is higher than high-speed ultra-light engines.
* High power requirements for hydraulic-power transmission system.
* Too heavy for a man to carry.
* High fuel consumption.
* Mobility is limited, time required for repositioning.

Ergonomics

--- Best features ---

--- Least desireable features ---

* The weight of all the hydraulic tools, except the six-inch shear, are well within the established ergonomic parameters.
* The hydraulic-powered winch(es) are available to perform work.
* Swing-control handle provides good leverage to guide the sled.
* The faller can perform all work in an upright position.
* Using the six-inch hydraulic shear head, both-hands are free to guide the falling stem.

* Moving the sled without power would be very very difficult.

SLED-MOUNTED PORTABLE POWER-UNIT and TOOL-CARRIER (cont.)

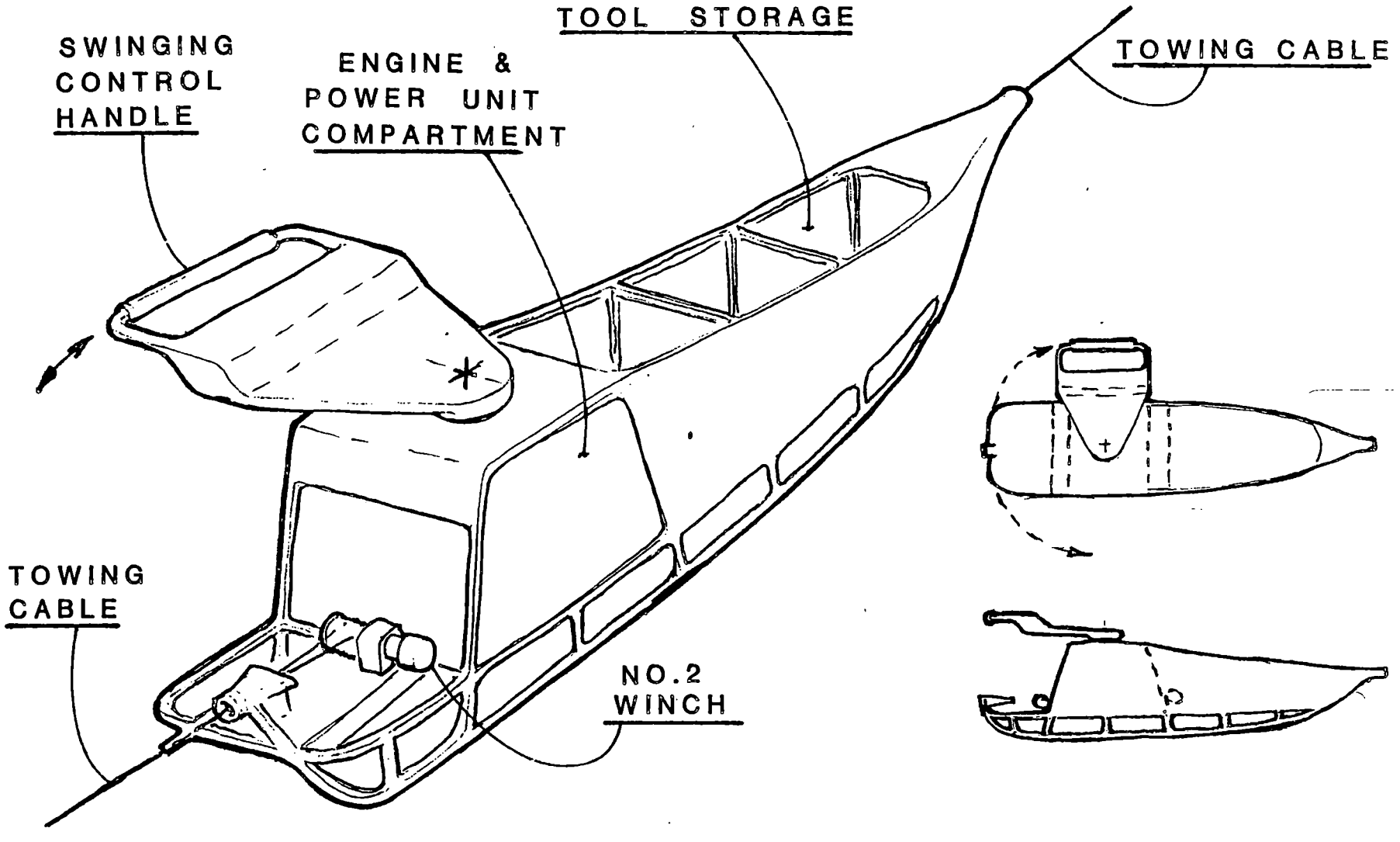
Personnel enviroment

--- Good features ---

* Reduced noise and engine fumes in near proximity.
* Minimum hydraulic chain-saw vibration.
* No shear vibration.
* The safest hand-tools available.
* Versatile and easily handled tools.
* High power source to; lift, pull, bunch, squeeze. haul, etc. when required.

--- Undesireable characteristics ---

* The hydraulic hoses can become entangled. [automatic rewinding reels could reduce the tangled hose problem.]



SLED MOUNTED
PORTABLE POWER UNIT & TOOL CARRIER

Figure 40. Two winches to pull and maneuver the Portable-Power-Pack Sled on steep and difficult terrain, may also be used for skidding and material handling.

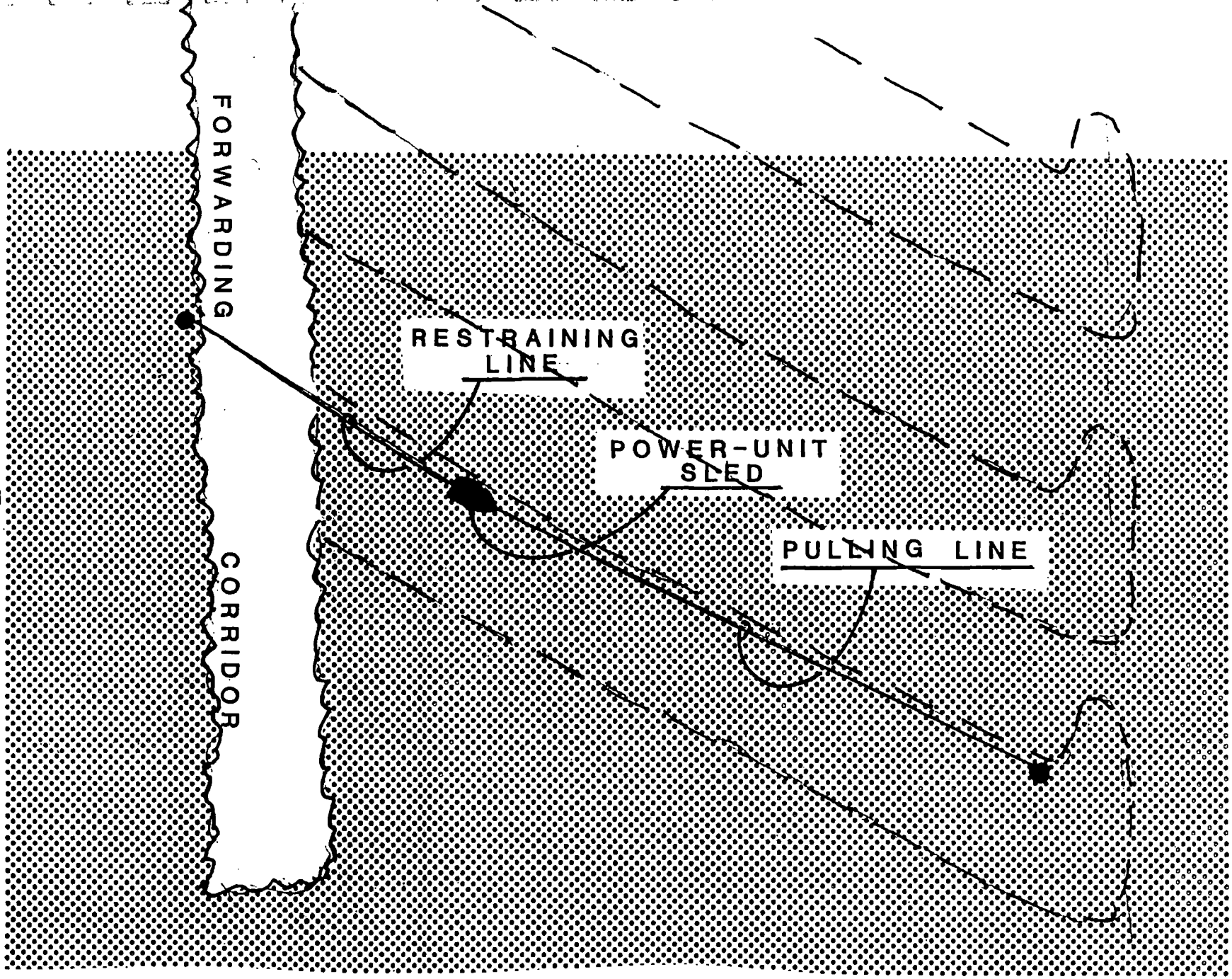


Figure 41. The sled-mounted portable power-unit is self-pulled into the stand to begin the thinning operation. On steep terrain a restrainning line is applied to prevent the sled from overrunning the pulling line.

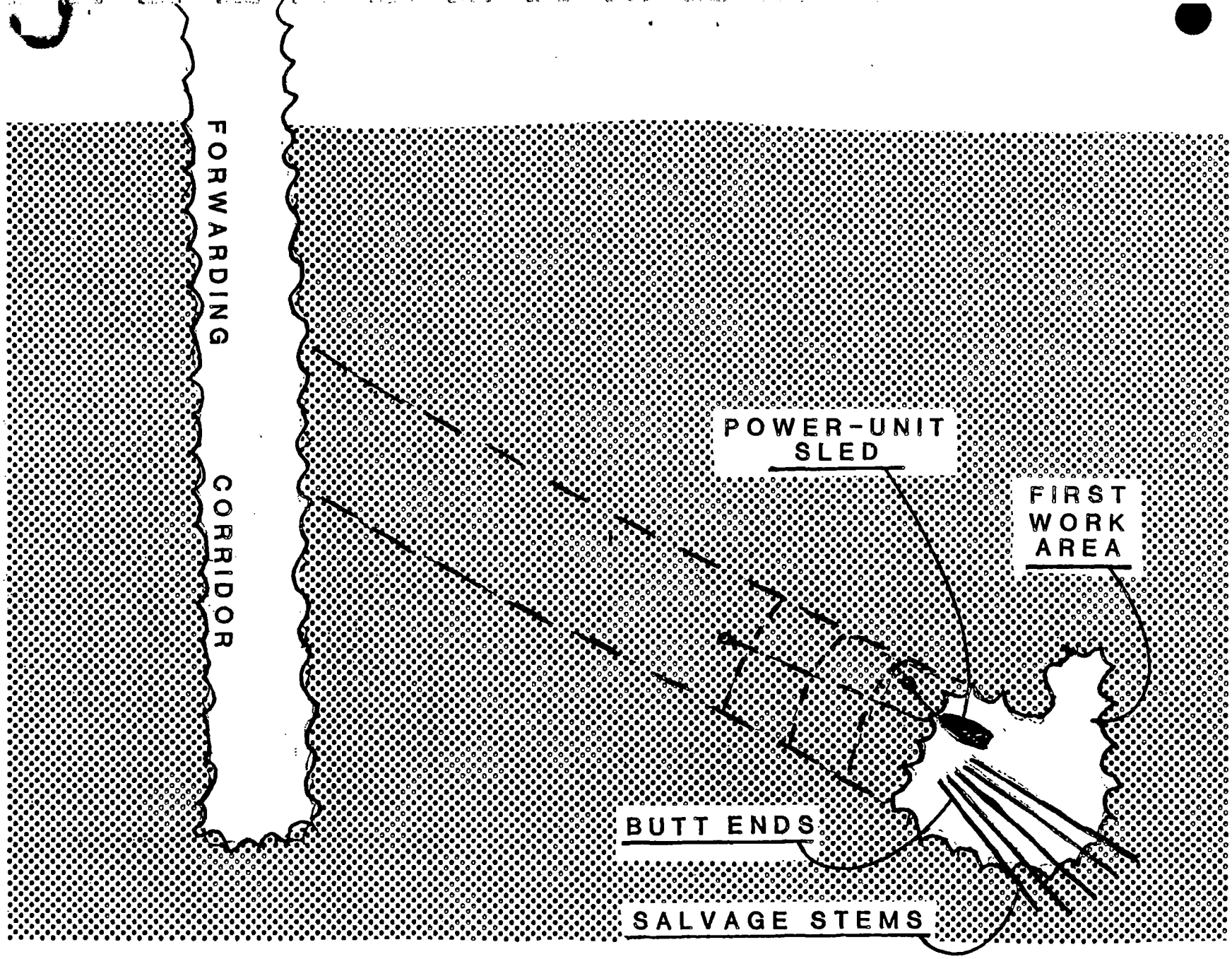


Figure 42. At the end of the thinning corridor the stems are piled to the downhill side of the work area with the butt ends toward the forwarding corridor.

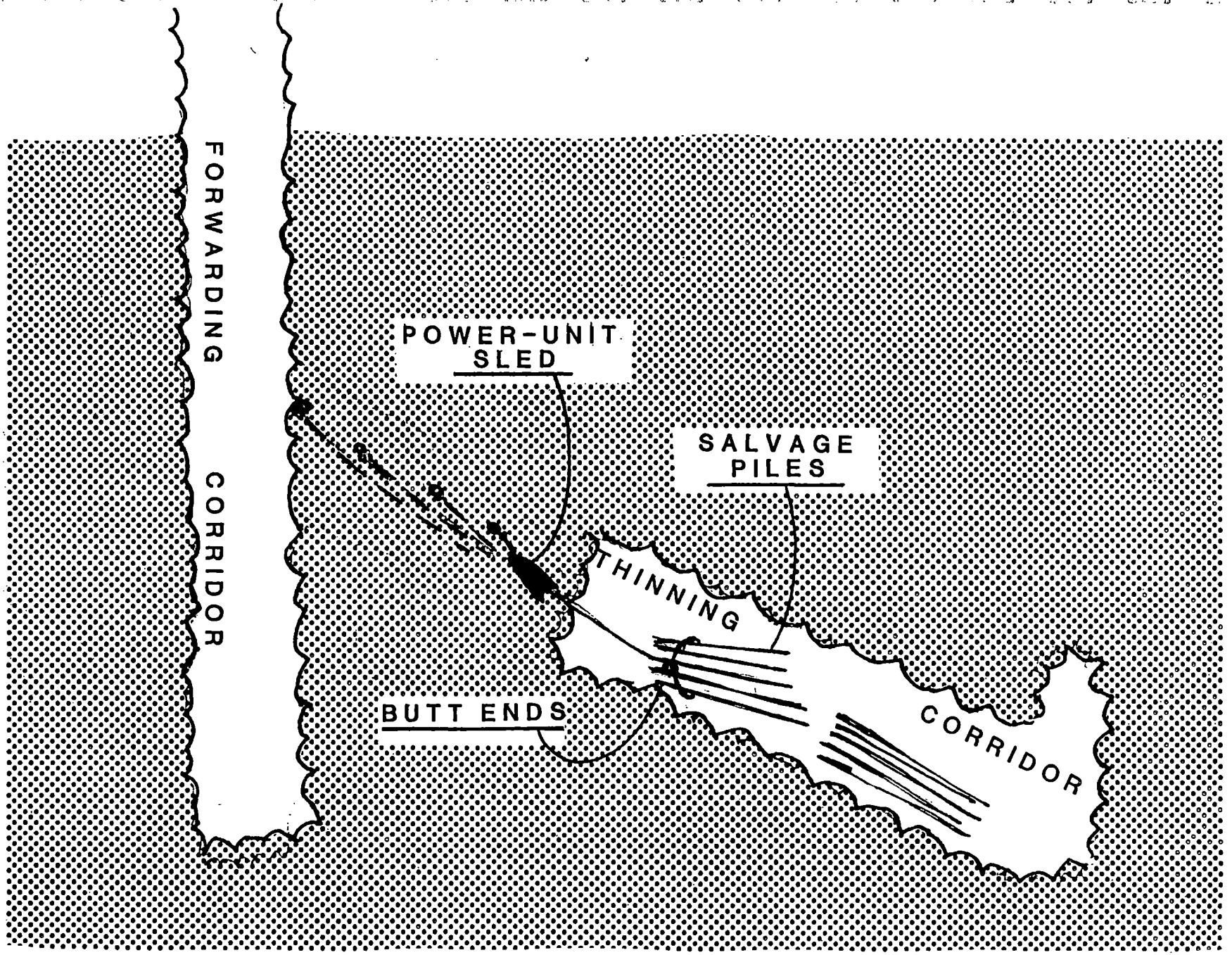


Figure 43. As thinning progresses towards the forwarding trail, the piles are pulled forward with the sled mounted winches.

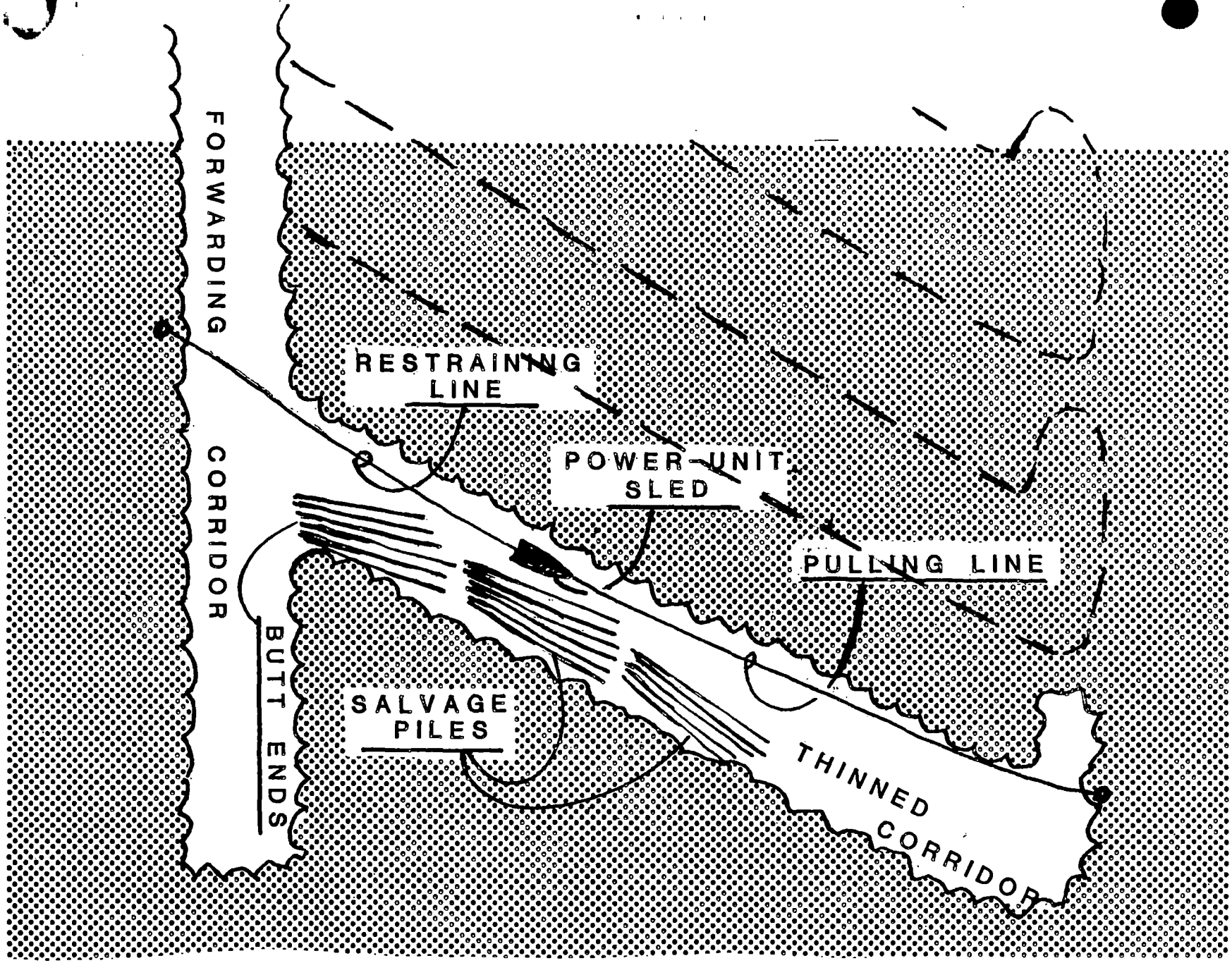


Figure 44. After the thinning corridor is complete, the salvaged-material piles are pulled close to, or into the forwarding corridor. The portable power-unit sled is then moved down the open corridor, and up into the next thinning area to continue the thinning task.

OUTLOOK OF PROFESSIONALS

Thinning contractors, pole-cutters and small-tree fallers are ususally individuals or members of small teams with very little capitol, who seem to rely on determination and hard-work to make the task pay. ("profit-ability","return on investment", etc. are not significant terms.)

Professionals interviewed who perform the manual task of felling and thinning small trees are definately interested in tools, methods and devices to make the job easier, - - but, initial cost is one of the most important considerations. Competition from non-professionals ("weekenders""part-timers) and unseasonned over-optomistic contractors, who can easily get "into" and "out of" the business with very little investment, makes it difficult to justify spending money on "convience" devices.

The current basic three markets for stems smaller than six-inch diameter are:

- ☐ POST and POLES
- ☐ WOOD FIBER
- ☐ BIOMASS FUEL

The subsidized indirect "STAND IMPROVEMENT" market is difficult to measure. The benifits are intangible and not well defined or based upon strong economic and sivicultural data, consequently it is difficult to justify and/or factor into special tool development costs.

The only real market for small hand-felled stems selectively handled is the post and pole market. But, the post and pole yards are generally low-volume, labor-intensive processors that cannot afford or justify long-term, high-volume contracts. The post and pole market is specialized and small, with significant competition from substitute materials. It is estimated that even if raw material and production costs are lower the market would not expand significantly.

Some processors and market specialists believe that dramatically improved products; such as very-straight, smooth, dimensionally-true and accurate rounds, could have value as architectural building products, and create a significant "NEW" high-volume market.

Wood-fiber and biomass-fuel markets both have significant growth potential and require very large volumes of low-cost material, but to serve these markets, total mechanization is the only option that can justify recovery and use of the small-stem resource.

The following is a summary of some views and comments expressed by some professional small-tree fallers, foresters and associated industry people, about the available tools and the idealized concepts presented and/or discussed in this report:

- General note
  - In all interviews the question of cost was raised as a major concern.

- Chain-saw on extended torque arm, figures 12, 13, and 14.
  - Lack of versatility.
  - Two-hands required at all times to perform the work.
  - Cutting-chain too susceptable to damage.
  - Some concern for safety.
  - Too much tool rotation required.
  - Concern about pinching or binding the blade.
  - Difficulty in making a backcut in some situations.

- Chain-saw on long reach-arm, figures 10, 16 and 17.
  - Concern about kick-back and safety.
  - Concern about the reliability of the cable drive. (Reliability of conventional chain-saws is already too big a problem.)
  - Cutting chain too susceptable to damage.
  - Most likely, two-hands would be required most of the time.
  - A bow-bar may work better than the long-bar illustrated.

- Disliked the engine upon the back because of:
  - Vibration.
  - Noise.
  - Fumes.
  - Spilled oil and fuel.
  - Heat.
  - Starting and stopping.
- Difficulty of setting the tool aside.
- Concern about maneuverability in dense stands and around hazards.

☐ Belt-saw in wishbone frame, figures 30 thru 35.

- Many could not appreciate the principal or rational.
- Lack of versatility.
- Concern for reliabilty.
- General indifference.

☐ Chain-saw with bow-bar, modified for stiff-leg, figures 36 thru 39

- Most were compelled to admit some positive features.
- All wanted a demonstration to show and/or trial test for;
  - Maneuverability.
  - Productivity.
  - Comfort.
  - Practicality.
  - Reduced effort.
- Most would be willing to try the idea.
- Some concern for stability, safety, and cutting-chain damage when the handle was released and the bow-bar allowed to rest upon the support-horns.
- Limited versatility for lopping, bucking, limbing, etc.
- Very few have seen or even used a bow-bar.

- Sled-mounted portable power-unit and tool-carrier, figure 40.
  - Wide variety of reactions from indifference, distain, to enthusiasm.
  - The enthusiast felt the shears tolerance to dirt, abuse and infrequent sharpening would be a big plus.
  - Liked the high probability of having both hand free when shearing the six-inch stems.
  - General belief that the hydraulic tools would be more reliable and rugged.
  - Most felt having the cable-power available close at hand would be desireable.
  - Hydraulic hoses would be a problem, but not serious.
  - No desireable or justifiable reason for two fallers working from the same power source, but a hinderance.
  - The enthusiast would still have to be "sold" with a demonstration to see and/or trial to test;
    - Productivity.
    - Maneuverability.
    - Practicality.
  - Considerable concern over;
    - Size.
    - Cost.
    - Method of application.
    - Probability of higher production and recovery.

- Chain-saw - basic
  - Maintenance is very important, but reliabilty is always a big concern.
  - Cutting-chain damage and the need to frequently sharpen the tool is the biggest negative cost and lost time factor.
  - No one uses a chain-saw with bow-bar, few have seen them, Lack of awareness or knowledge of the bow-bar is the only apparent reason they are not used.

FUTURE DEVELOPMENT PRIORITIES

As a result of this study the following four concepts are considered viable options for further development:

- ☐ CHAIN-SAW ENHANCEMENT.
- ☐ WIRE and/or CABLE-SAW.
- ☐ PORTABLE HYDRAULIC-POWER PACK and TOOL-CARRIER.
- ☐ WALKING STEEP-TERRAIN TREE-FALLING MACHINE.

It is this Author's opinion,that to achieve the long-term objectives of the STEM program, the Walking Steep-Terrain tree-falling Machine (WST/TFM) or (WSTM) should receive the highest priority. However, to achieve the short term objectives of this Cooperative Agreement, the Portable Hydraulic-Power Pack and tool-carrier (PHPP) option should be developed first.

Chain-saw enhancement

Enhancing the basic chain-saw is the most immediate, low-cost way to achieve some improvement in the methodology of falling small trees; and achieve some of the Design Criteria objectives established by this cooperative agreedment.

To this end, the most credible concept is the "STIFF-LEG", which requires only minor modifications of a standard chain-saw with bow-bar. Several prototype "STIFF-LEG" devices could be easily fashioned to first prove the concept; develop some data on productivity; workout some mechanical and ergonomic features desireable for actual forest and falling conditions; and insure that the human-factor requirements of maneuverability, safety, comfort, etc. are achieveable. This relatively low-cost, short time-frame effort would then demonstrate the probability of acceptance and practicality.

If the prototype demonstration is positive, a manufacturer(s) could be encouraged to spend the money necessary for custom tooling, manufacturing, distribution, marketing, etc. Prototype testing and demonstrations to develop acceptance is a step that cannot be by passed.

Wire and/or Cable-saw development

Development of wire and cable-saw technology will require a high level of effort , but the low-power required by the very thin cable-saw, and potential tool design flexibility could create some very dramatic changes in cutting tool size and design, plus potentially effecting a wide range of other applications.

Development of the wire or cable-saw will require a major long-term research and development commitment to create a reliable, low-cost cutting device.

Portable Hydraulic-power Pack and Tool Carrier

If demonstrations can show the industry proffessionals that Portable Hydraulic-Power Packs (PHPP) can be moved on steep terrain, through dense stands, safely and efficiently, the use of very light-weight hydraulic-powered tools can become a reality. The reliable, rugged tools with a high-performance power-pack, has the potential to reduce physical effort, increase productivity, in addition to aiding recovery of the material, far better than any other manual sytem.

A ultra-light six-inch hydraulic shear-head would have to be design and built, but the other tools would only require minor modifications. However, to show the systems flexibility and performance capability, it would be necessary to build a prototype power-pack sled with two winches and a hydraulic system to deliver high-volume of oil at low-pressure, and then shift to low-volume at high-pressure.

Walking Steep-Terrain Tree-falling Machine

To achieve real high-volume low-cost production of small-trees, without destroying the forest, the Walking Steep-terrain Tree-Falling Machine (WSTM) must become a reality.

The machine must be able to negotiate slopes steeper than 60% (31^{o}); pass over very large obstacles, such as boulders, stumps, dead-falls, trash piles, etc.; and require no road construction. On steep terrain the WSTM

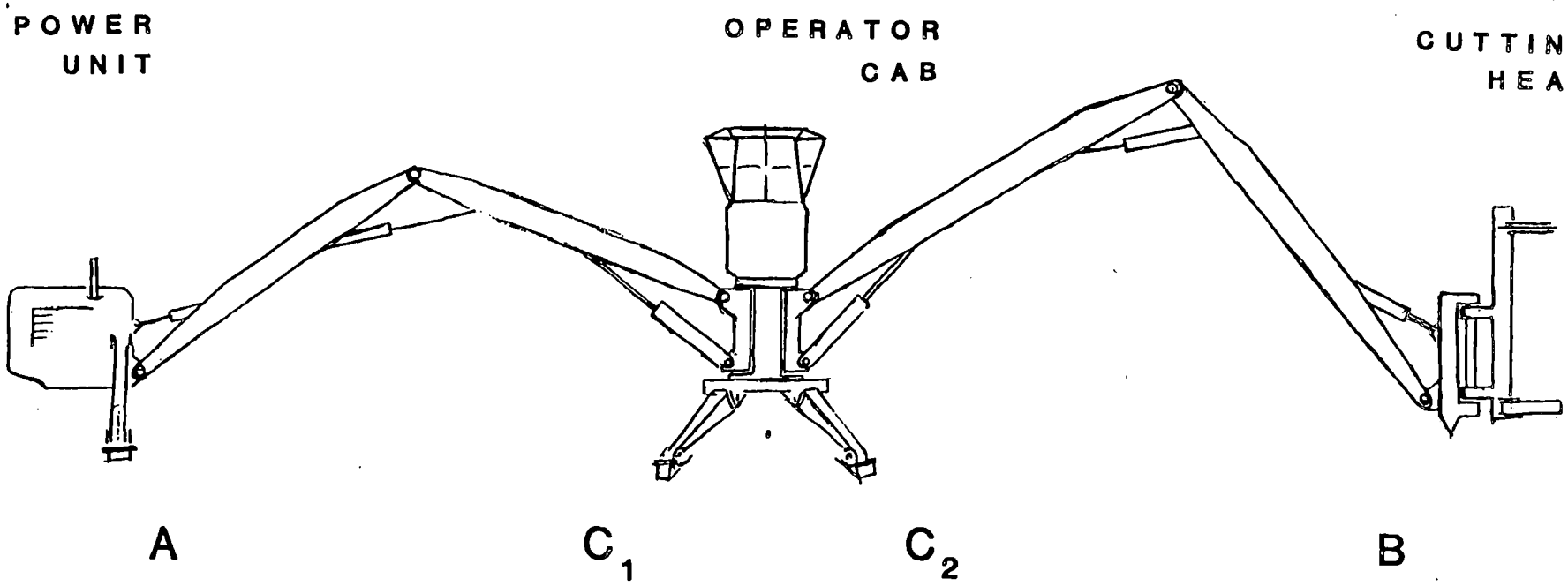
must move without scouring and tearing up the ground cover; have a low "weight/ground support" ratio; and create minimum damage to the ground cover.

The ability to bunch, pile, maneuver in very tight alleys, but reach to selected material without destroying and/or damaging the leave- trees is essential.

The technology is available. The ultimate cost should be less than any conventional feller-buncher, because the WSTM has no wheels, tracks, transmissions, fewer bearings, mechanisms and be much lighter in weight.

Implementing a program to develop the concept, can be organized around a Research and Development Limited Partnership (RDLP) with forestland owners, forest product processors, machinery manufactures, Forest Service and other interested groups contributing as RDLP members.

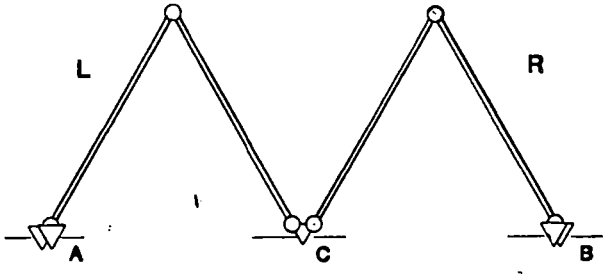
The "new" RDLP concept permits divergent and/or competative groups to cooperate in a way that shares the risks and rewards of the effort.



A WALKING STEEP - TERRAIN TREE - FALLING MACHINE

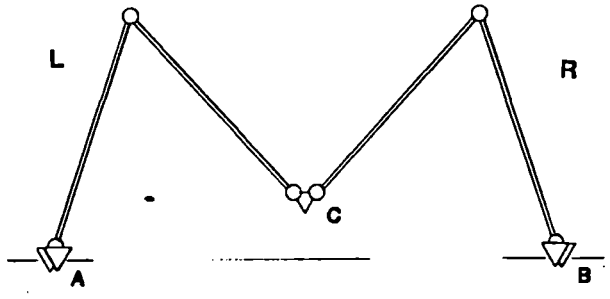
Figure 45. The Outriggers of the Operator's Cab, provide stability during operations and increases the distance between the Fulcrum "C_2" and counterbalance "A".

Movement sequence **1**



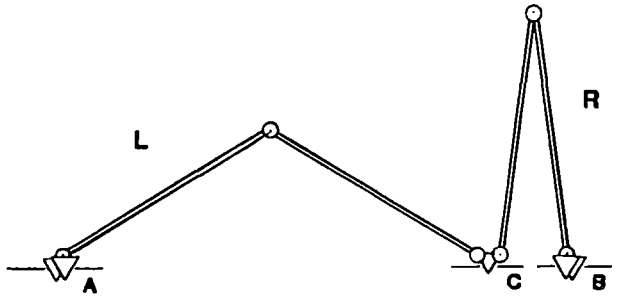
* NEUTRAL, rest position.

Movement sequence **2**



* Foot "C" raised clear of ground obstacles.

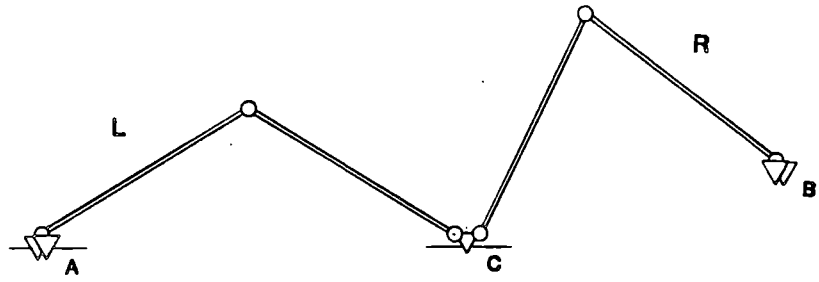
Movement sequence **3**



* Boom "L" expanded toward foot "B".
* Boom "R" contracted toward foot "B".
* Foot "C"lowered to the ground.

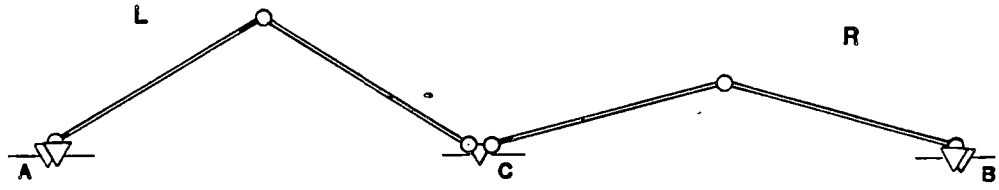
Figure 46. The Movement sequence begins by moving Point "C" [Operator's Cab] close to a foot ["B"].

Movement sequence 4



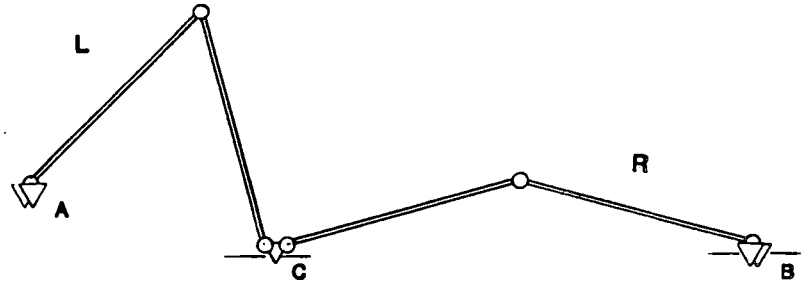
* Foot "B" raised clear of ground ostacles.
* Boom "R" expanded away from foot "C".

Movement sequence 5



* Foot "B" lowered to the ground.

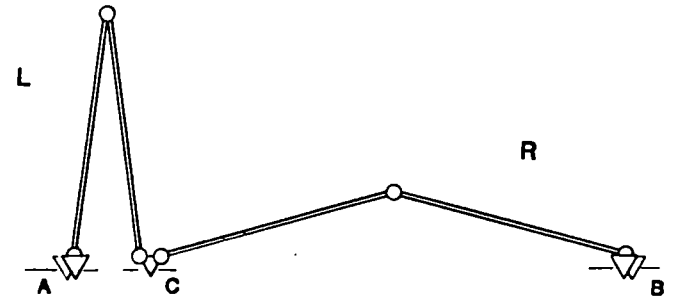
Movement sequence 6



* Foot "A" raised clear of ground obstacles.
* Boom "L" contracted toward foot "C".

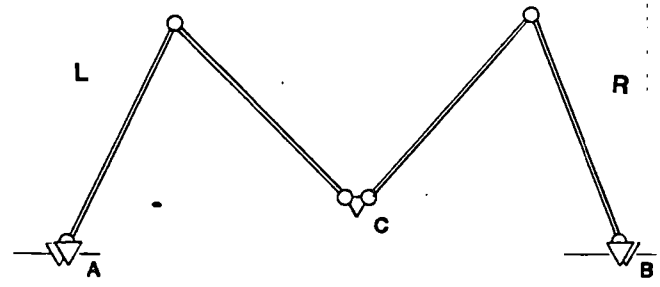
Figure 47. If the tool is on foot"B", sequence position "4" is the position in which work would be performed. To continue walking, foot "B" moves away from "C" and foot "A" moves toward "C".

Movement sequence 7



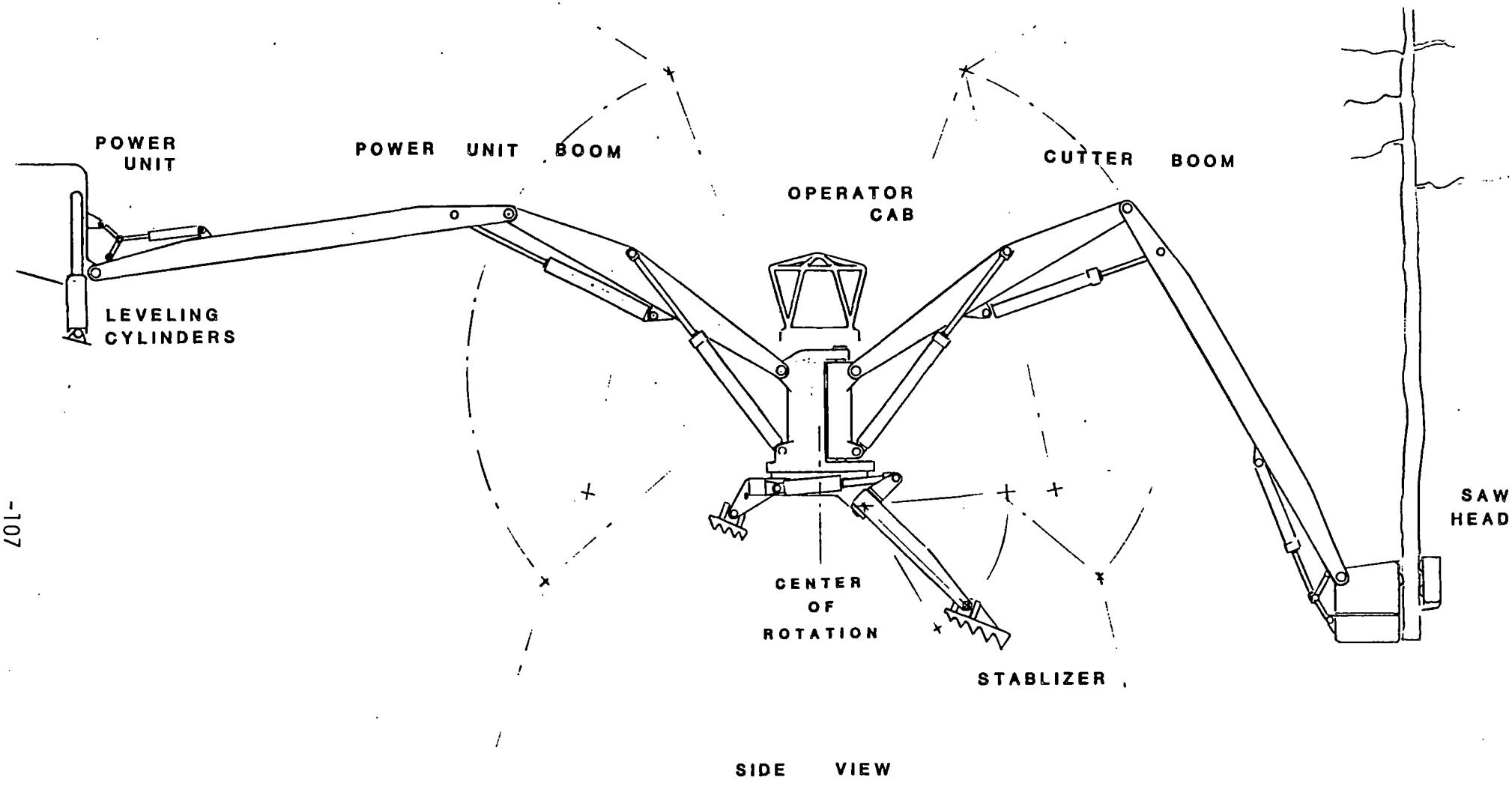
* Foot "A" lowered to the ground.

Movement sequence 8



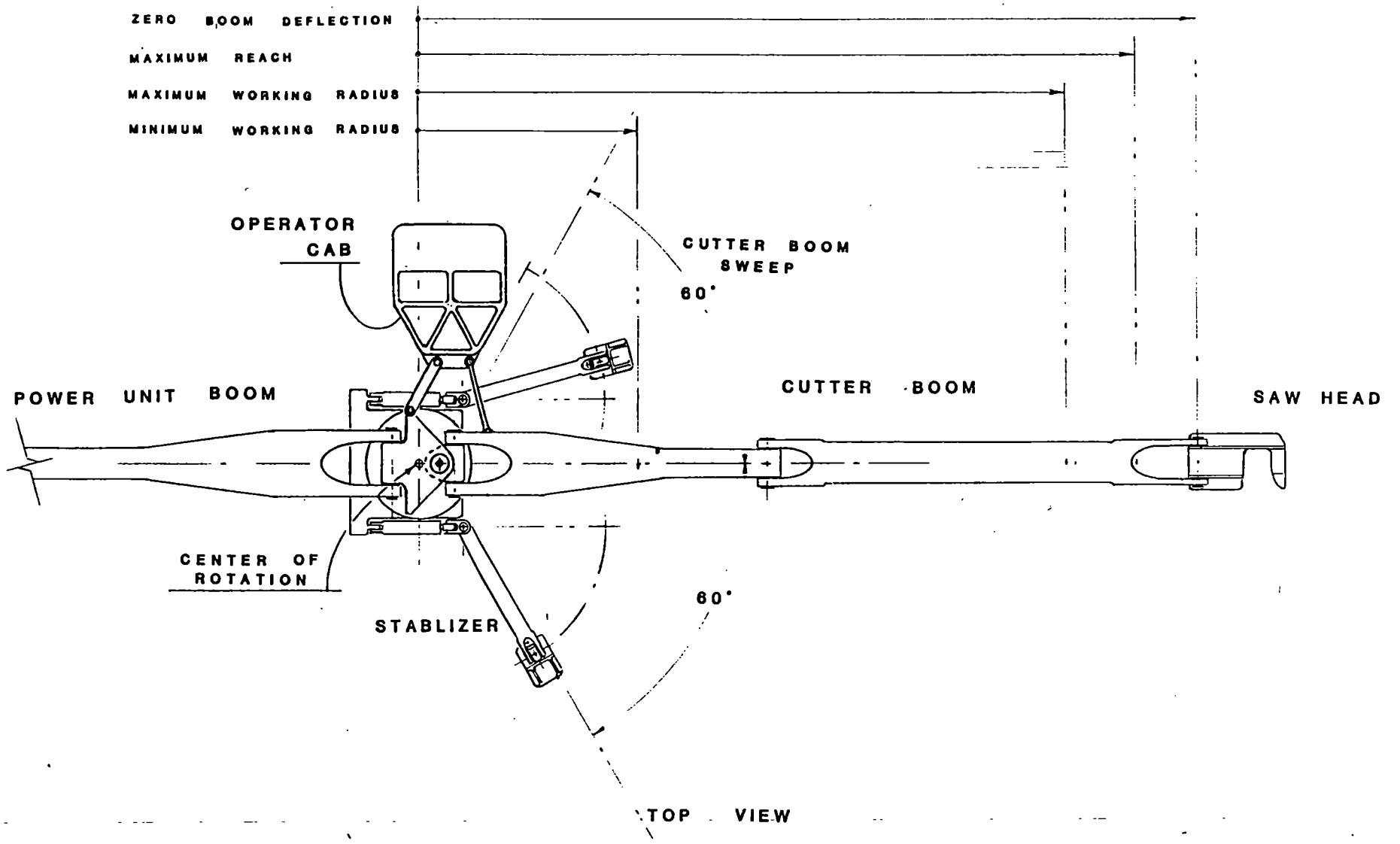
* Foot "C" raised clear of ground obstacles.
* Boom "L" expanded toward foot "B".
* Boom "R" contracted toward foot "B".

Figure 48. Sequence position "7" shows the maximum step length per movement. The direction of movement is controlled by swinging the Leg toward the travel path, before the foot is placed upon the ground.



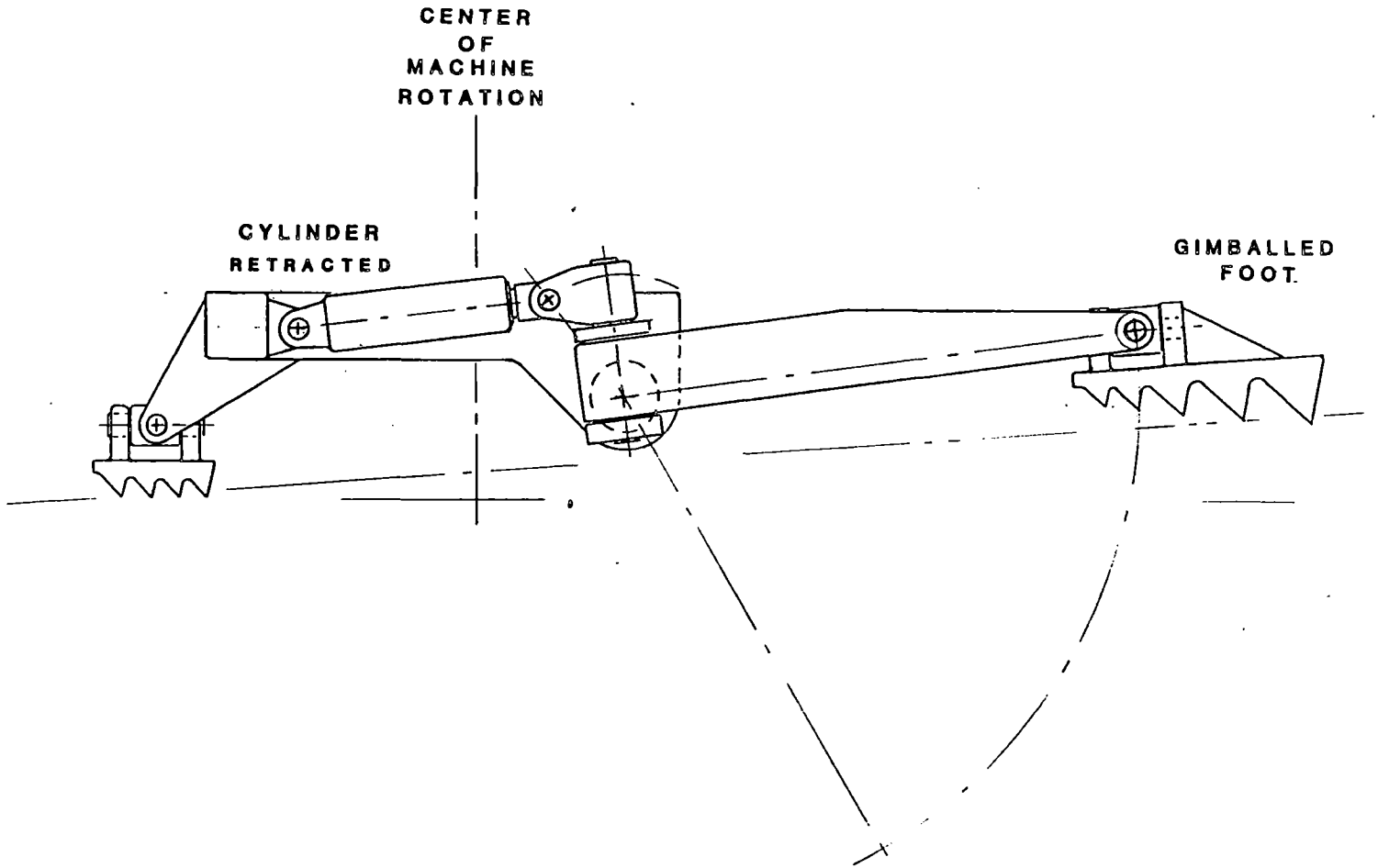
A WALKING STEEP - TERRAIN TREE - FALLING MACHINE

Figure 49. The Power-Unit has dual leveling-cylinders, so when the Saw-Head is placed upon the ground, the three-points form a stable base so the center section can rise and move to the next position.



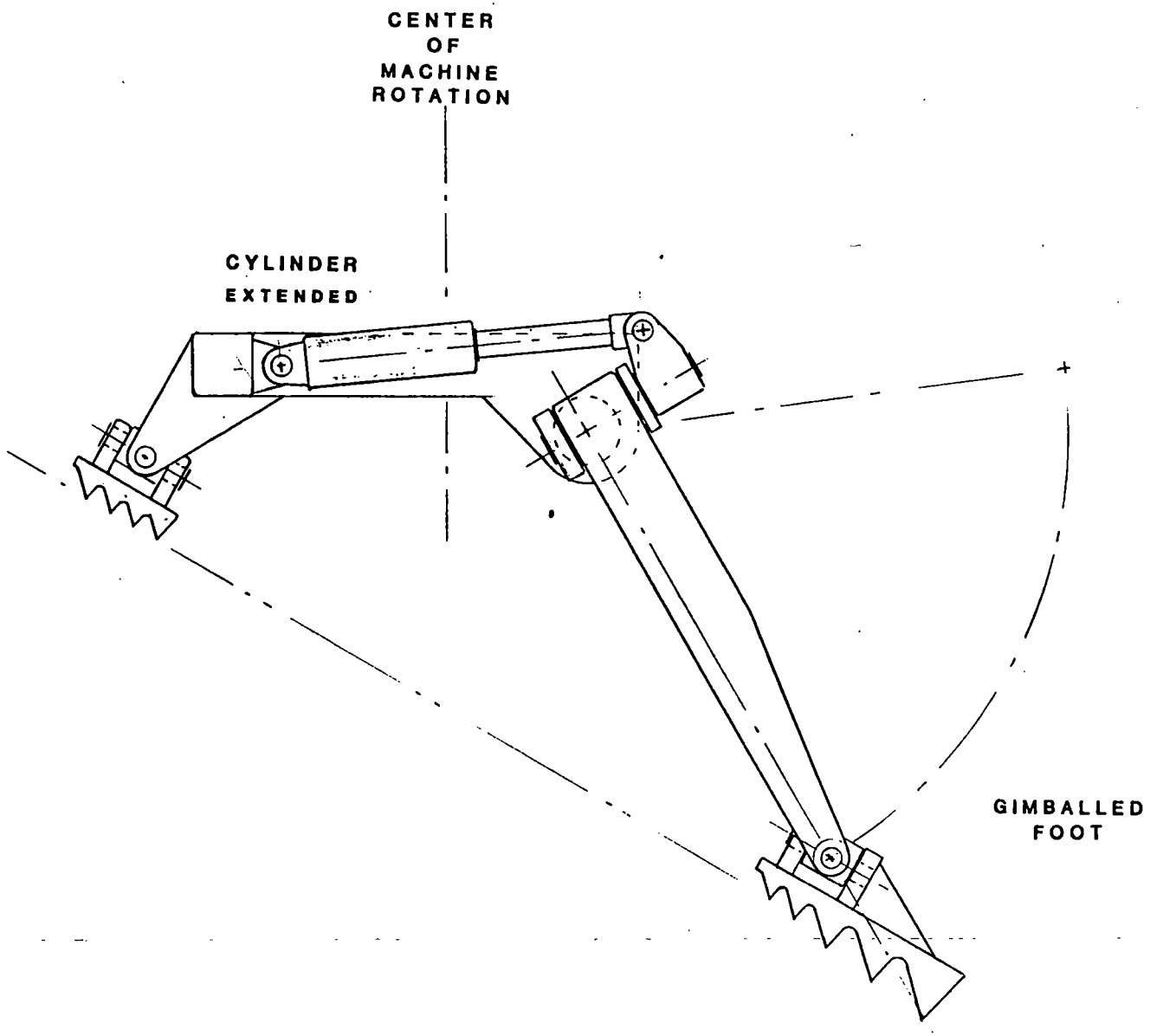
A WALKING STEEP-TERRAIN TREE-FALLING MACHINE

Figure 50. The stablizer legs can be swung In and Out relative to the leveling base, but the leveling platform also rotates 360° relative to the cutting boom.



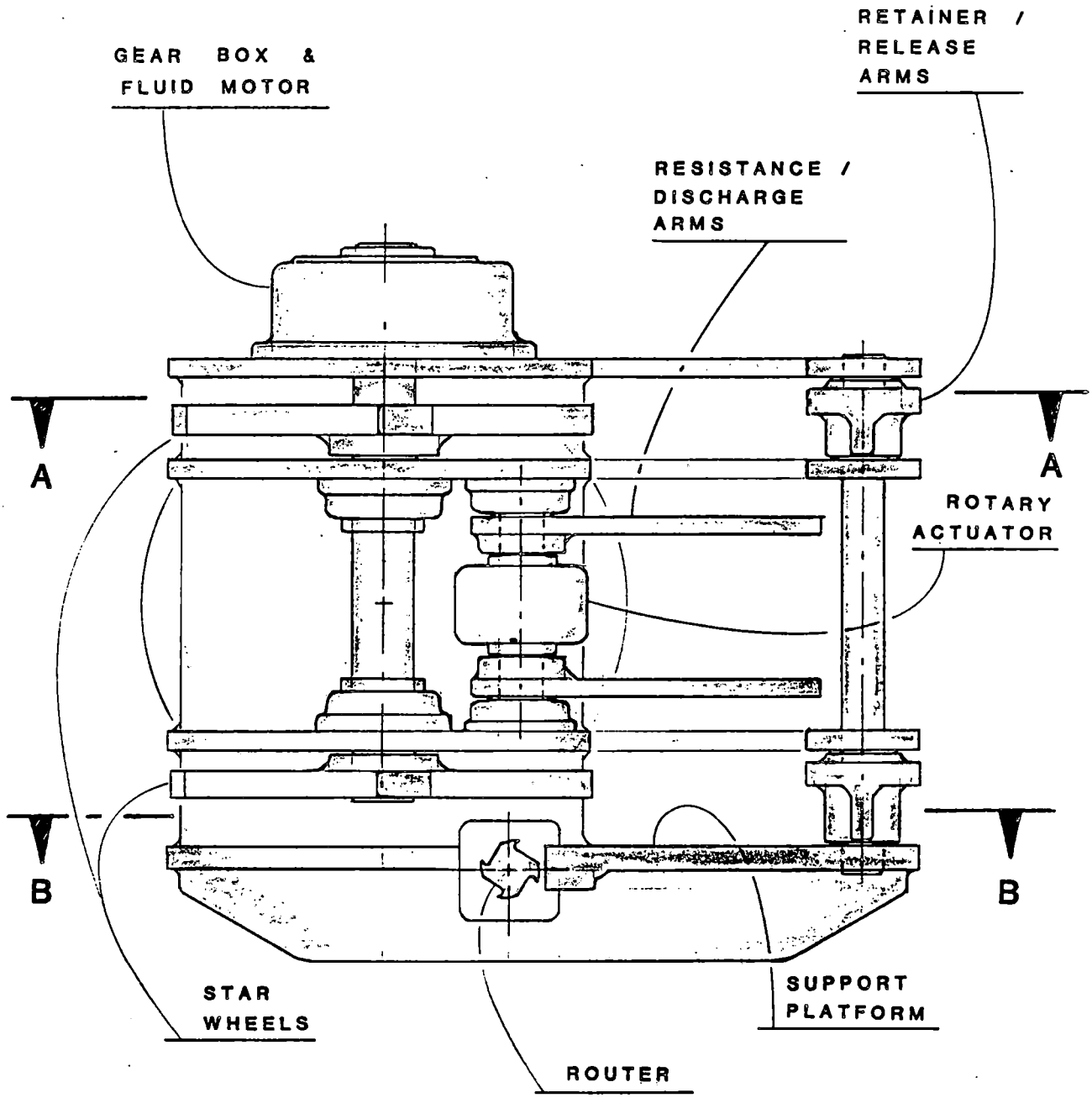
A LEVELING & STABLIZING MECHANISM

Figure 51. Movement in any direction is possible by rotating the leveling and stablizing mechanism under the walking machine base.



A LEVELING & STABLIZING MECHANISM

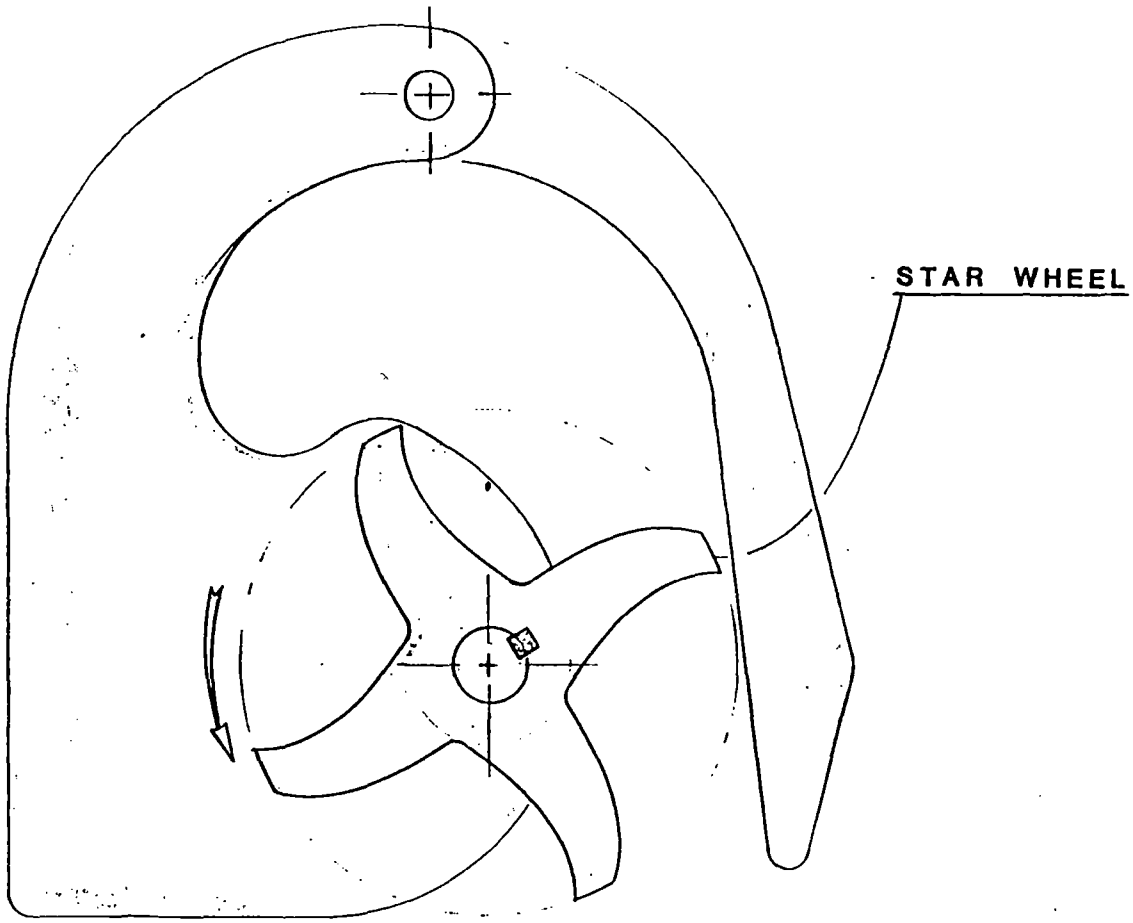
Figure 52. Operation on steeper inclines can be accomplished by increasing the length of the downhill leg, and modifying the gimballed foot.



FRONT VIEW SECTION

ROUTER - SAW HEAD WITH ACCUMULATOR

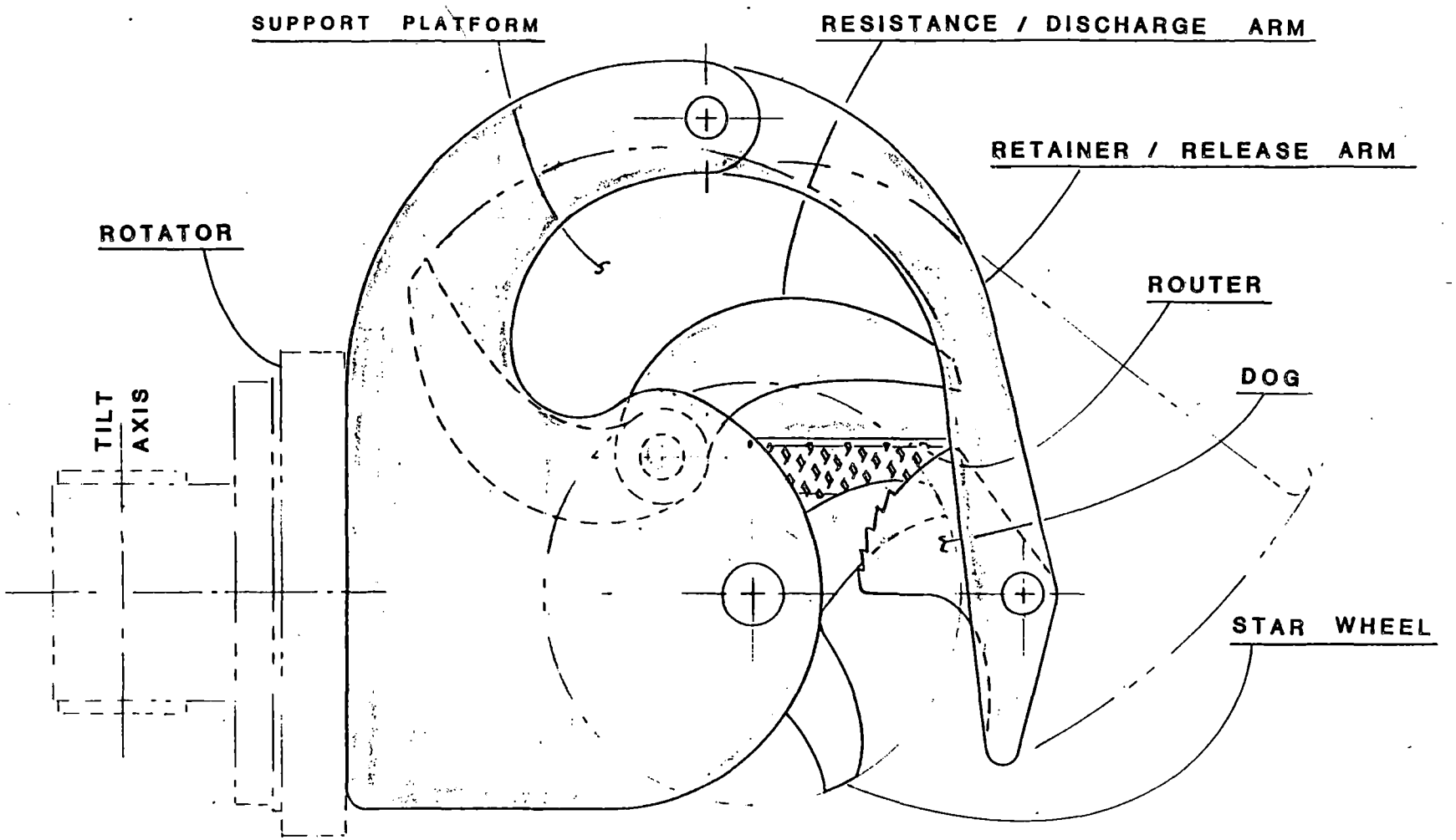
Figure 53. The Support Platform thickness is less than the Router Kerf, so the platform passes under the stem and provides support while cutting the stem.



TOP VIEW SECTION A – A

STAR WHEEL FOR ACCUMULATOR

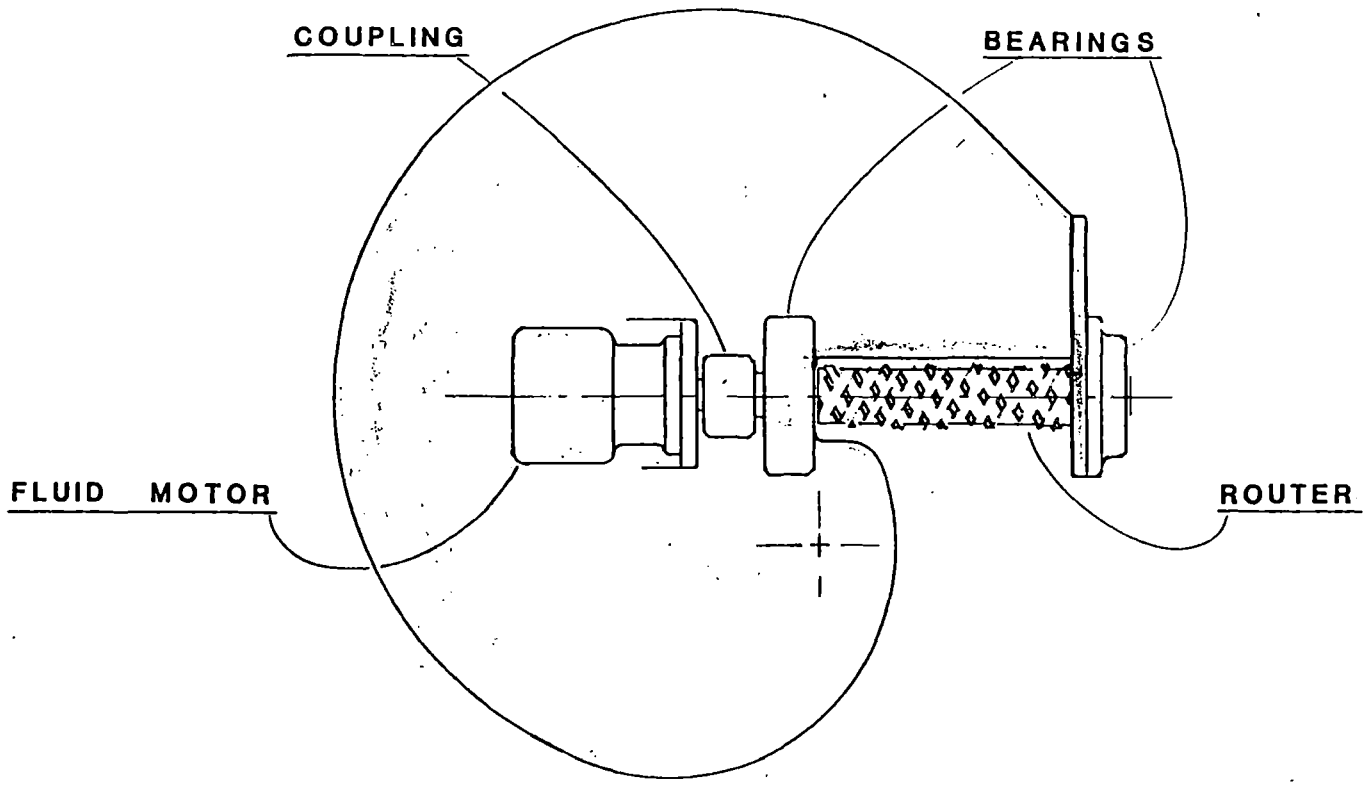
Figure 54. Rotating the Star-Wheel, pushes the cut stems into the Accumulator-Cavity.



TOP VIEW

ROUTER - SAW HEAD WITH ACCUMULATOR

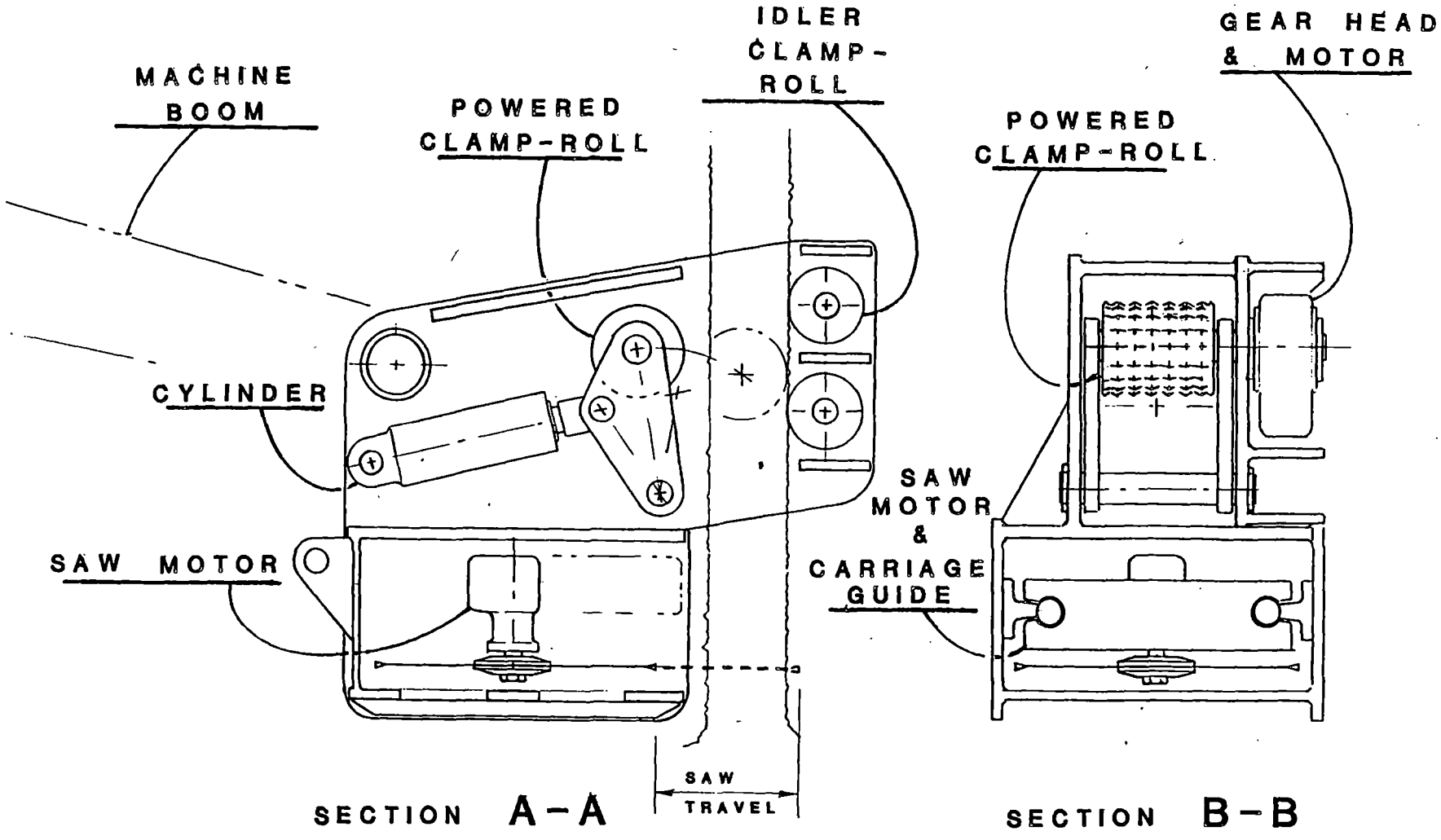
Figure 55. The "Dog" prevents the small stems from falling away, while the Resistance-Arm keeps the stems clustered and vertical. The stems can be dumped when the Release-Arm is opened, and Discharge-Arm actuated.



TOP VIEW SECTION B - B

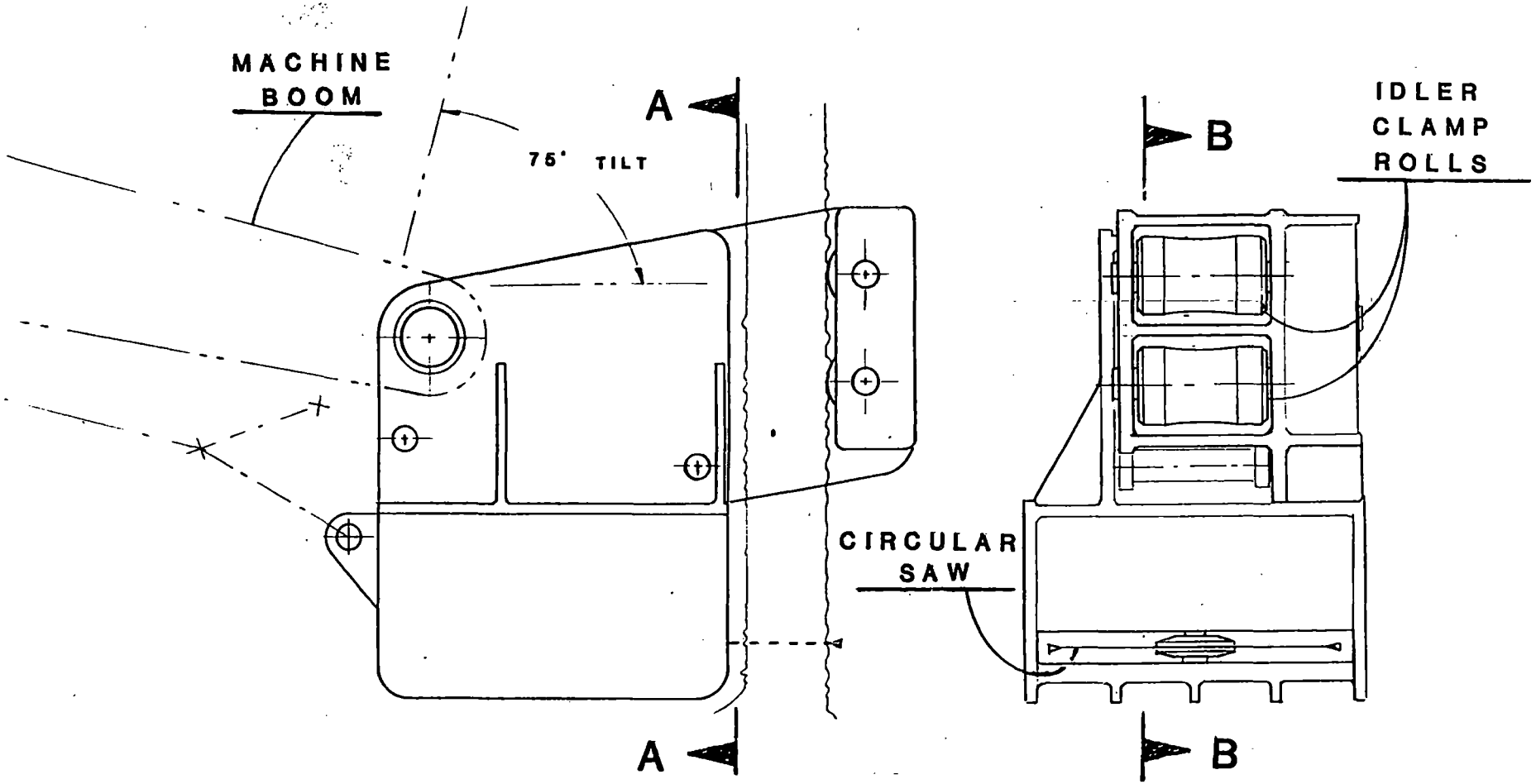
ROUTER - SAW

Figure 56. The Accumulator-Area beside the Router supports the cut stems, after they are cut and pushed into the area by the Star-Wheel.



CIRCULAR-SAW FALLING-HEAD, MACHINE MOUNTED

Figure 57. The Powered Clamp-Roll can apply a lifting force upon the stem to prevent the Saw-Blade from being pinched, while cutting and retracting.



CIRCULAR-SAW FALLING-HEAD, MACHINE MOUNTED

Figure 58. The Falling-Head must tilt and twist so leaning trees can be approached from all angles, and then when cut, laid upon the ground.